Filmwise Condensation of Steam on Horizontal
Wire-Wrapped Smooth and Roped Titanium Tubes

by

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Results obtained for the wire-wrapped smooth titanium tubes showed a maximum enhancement of 30% as compared to a smooth titanium tube. This was for a tube using a 0.5 mm wire diameter (P/D = 7.92), corresponding to a fraction of the tube covered by the wire of 12%. The LPD KORODENSE titanium tube showed an enhancement of 20% compared to a smooth titanium tube for both atmospheric and vacuum pressures. The addition of wrapping a wire in the grooves of the LPD tube showed no further significant enhancement for the three wire dianmeters tested.

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ABSTRACT

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NOMENCLATURE

a	as defined in equation (4.23)
A_i	effective inside surface area, m^2
A_o	effective outside surface area, m_2
b	as defined in equation (4.22)
c	as define in equation (4.15)
C_i	leading coefficient for the inside heat transfer correlation used
C_p	specific heat at a constant pressure, J/kgK
d	as defined in equation (4.15)
D_i	tube inside diameter, m
D_o	tube outside diameter, m
E_T	enhancement ratio based on ΔT
F	fraction of the tube covered by wire
F^*	as defined in equation (2.3)
g	gravitational constant, 9.81 m/s
h_{fg}	specific enthalpy of vaporization, J/kg
h_i	inside heat transfer coefficient, W/m^2K
h_o	outside heat transfer coefficient, W/m^2K
k_c	thermal conductivity of the coolant film, W/mK
k_f	thermal conductivity of the condensate film, W/mK
k_m	thermal conductivity of the tube material, W/mK
K_1	as defined in equation (4.16)
K_2	as defined in equation (4.16)

L	active length of tube exposed to steam, m
L_1	length of inlet portion of tube, m
L_2	length of outlet portion of tube, m
LMTD	log mean temperature difference, K
$\dot{m}$	mass flow rate of the coolant, kg/s
Nu	Nusselt number
P_{sat}	saturation pressure, Pa
Pr	Prandtl number
Pr_w	Prandtl number at the wall temperature
Q	heat transfer rate, W
q	heat flux, W/m²
Re	Reynolds number
Re_f	Reynolds number for the condensate film
$Re_{2\theta}$	two phase Reynolds number
R_i	inside thermal resistance, m²K/W
R_o	outside thermal resistance, m²K/W
R_{total}	total thermal resistance, m²K/W
R_w	wall thermal resistance, m²K/W
T_{cf}	temperature difference across the condensate film, K
ΔT_f	temperature difference across the film, K
T_{sat}	vapor saturation temperature, K
T_1	cooling water inlet temperature, K
T_2	cooling water outlet temperature, K
U_o	overall heat transfer coefficient, W/m²K
U_∞	vapor velocity, m/s
V_w	velocity of the coolant, m/s

X	as defined in equation (4.19)
Y	as defined in equation (4.18)
Z	as defined in equation (4.12)

Greek Symbols

α	dimensionless coefficient
ϵ	as defined in equation (4.16)
μ_c	dynamic viscosity of the coolant, kg/m s
μ_f	dynamic viscosity of the condensate film, kg/m s
μ_w	dynamic viscosity of the condensate at the wall, kg/ms
ρ_f	density of the condensate film, kg/m^3
ρ_v	density of the vapor, kg/m^3
η	surface efficiency
Ω	as defined in equation (4.13)

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I. INTRODUCTION

A. BACKGROUND

Since the Cold War has ended, the money allocated for new weapon platforms in the Navy has been greatly reduced. There is therefore an increased emphasis on making ships as cost efficient as possible. Technology has progressed to the point where the heat removal requirements of modern weapons systems have increased. Future classes of attack submarines are expected to be smaller in size and just as capable as the existing 688 class. This will require the main and auxiliary propulsion systems to be designed for maximum power with the smallest, lightest, and most cost efficient components. One method to reduce the main propulsion system size and weight is to use enhanced tubing in the main condenser. In addition, submarine and surface ship refrigeration systems can have larger capacities, and maintain the same approximate size and weight if enhanced tubing is used in the refrigeration condenser. The Naval Postgraduate School, with support from the David Taylor Research Center, has been conducting research on various types of condenser tubing with the object of designing smaller, lighter, and more efficient condensers.

The DDG-51 class of destroyers was originally designed to have enhanced titanium tubes used for the refrigeration

condenser to give significant weight reduction to the refrigeration plant. In submarines, the use of enhanced titanium tubes in the main and auxiliary condensers would lead to a major reduction in weight of the steam propulsion plant. Titanium has the advantage over copper-nickel, which is presently used in condensers, of a higher strength to weight ratio, as well as excellent corrosion and erosion resistance. This allows for thinner tube walls and higher coolant flow rates to be used, so the same overall amount of heat can be transferred [Ref. 1]. The improved performance of enhanced tubes allows the same amount of power to be produced at a lower turbine backpressure, allowing for the design of smaller, more efficient propulsion plants. Alternatively, a larger power output can be achieved at the same backpressure for a plant of the same size. Some of the disadvantages of titanium are that it has a much smaller thermal conductivity and it is very expensive compared to copper-nickel.

B. CONDENSATION

Condensation occurs when a vapor is cooled below its saturation temperature, or when a vapor/gas mixture is cooled below its dew point. Condensation also occurs when a vapor comes into contact with a subcooled liquid. This is known as direct contact condensation. The most common type of condensation involved with heat exchangers is surface condensation. This occurs when the vapor contacts a surface

that is maintained below the saturation temperature of the vapor. Two types of surface condensation can take place. The first is filmwise condensation, so called because the condensate "wets" the surface with a continuous film. The second is dropwise condensation, so called because the condensate does not "wet" the surface, but instead forms distinct droplets of various sizes. Microscopic droplets coalesce to form large drops, which are then removed from the surface by gravity and/or vapor shear forces. Dropwise condensation results in much higher heat transfer coefficients (typically by an order of magnitude) than with filmwise condensation due to the fact that a certain portion of the cooled metal surface is exposed to the vapor. However, dropwise condensation is difficult to maintain over the life of a typical condenser. Many attempts have been made to promote dropwise condensation by using special surface coatings, but these tend to get 'washed' off in the little long term, reverting back to filmwise condensation. Therefore, condensers are normally designed to operate assuming filmwise condensation takes place, Thus providing for a conservative design [Ref. 2].

The heat transfer rate across a condenser tube is controlled by the tube wall, fouling, coolant side, and vapor side thermal resistances. For most laboratory experimental work, the tubes are thoroughly cleaned before testing, so the fouling thermal resistance is negligible. The other thermal

resistances vary depending on the condensing and coolant fluids used, tube geometry and material, and the flow conditions of the coolant and vapor. During condensation of steam, the coolant side thermal resistance is usually the dominant controlling resistance.

Methods of lowering the coolant side resistance include the use of inserts and roped tubes. However, any increase in heat transfer is offset by an increase in the pressure drop along the tube. Although inserts provide the best enhancement, the large pressure drop involved generally restricts their use to laminar flows and other specialist applications. Roped tubes, which tend to incur a much lower pressure drop, have been used successfully in a large scale condenser at the Gallatin Unit 1 300-MW power plant for the Tennessee Valley Authority. Low pressure drop (LPD) KORODENSE 90-10 Cu-Ni tubes were used to retube the condenser in August 1980 (LPD KORODENSE is a particular type of roped tube made by the Wolverine Tube Co.). Although it cost about $65,000 more to retube using the roped tubes, a projected savings of $908,000 is expected over the remaining life of the plant based on actual performance [Ref. 3]. The wall resistance is controlled by the type of material used and the thickness of the tube wall.

The vapor side thermal resistance is lowered essentially by thinning the condensate film. One way of thinning the condensate film can be achieved by changing the geometry of

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the outside surface of the tube to utilize the surface tension effects of the fluid. Thinning the condensate film can significantly increase the heat transfer, especially for fluids like water where the surface tension is high. The use of fins, wire-wrap, and roped tubes have all been used to lower the vapor side resistance by causing an uneven pressure distribution through the condensate film on the surface of the tube.

C. CONDENSATION RESEARCH AT THE NAVAL POSTGRADUATE SCHOOL

The Naval Postgraduate School (NPS) has been conducting condensation research on enhanced tubes since 1982. Van Petten [Ref. 4] provides a summary of the research efforts on single horizontal tube condensation at NPS from 1982 to 1988. In particular, the research has looked at many aspects of enhancing tubes with low integral fins. Previous researchers have varied the fin spacing, fin shape, fin material, and tube diameter to determine how the performance of the tube is affected. Work has been done on single tubes and tube bundles at various pressures. Several different types of working fluids have also been used: steam, R-113, and ethylene glycol. All of this has been done to determine if the performance of an enhanced tube can be predicted, and under what condition the maximum enhancement will be realized.

Previously, the modified Wilson plot technique has been used to find the outside heat-transfer coefficient. However,

without an accurate inside heat transfer correlation, past researchers have had trouble reducing their data to provide an accurate value of the outside heat-transfer coefficient. Swensen [Ref. 5] used an instrumented tube to find the values of the tube wall temperatures. With a mean wall temperature of the tube, the inside and outside heat-transfer coefficients could be calculated directly. He then developed several inside heat transfer correlations using his data, based on the form of the Sieder-Tate [Ref. 6] correlation. His research noted that the outside heat transfer correlations were very sensitive to the Reynolds number exponent.

1. **Condensation Research Using Roped and Wire-Wrapped Tubes**

Most of the single tube condensation research done previously at NPS has involved the use of smooth and low integral fin copper tubes. Only a few researchers at NPS have studied the effects of wire-wrapping smooth tubes in a condensation application. The first was Kanakis [Ref. 7] in 1983. He tested titanium smooth and roped tubes, both with and without wire wrapping, while condensing steam in a vertical in-line tube bundle; up to 30 tubes were simulated by using inundation tubes. Brower [Ref. 8] used the same apparatus as Kanakis to try and determined the effects of wire diameter and pitch on the steam side heat transfer coefficient and to compare the effect of condensate inundation on smooth

and wire-wrapped tubes. Kanakis and Brower showed that the wire-wrapped tubes were not significantly affected by inundation (i.e. the wire provided better drainage down the bundle) in a steam condenser bundle. In a different apparatus, Mitrou [Ref. 9] conducted research on single tubes, both finned and wire-wrapped. He studied the relationship between the wire pitch and wire diameter for several wire-wrapped smooth copper tubes. Mitrou's results showed that the enhancement of a wire-wrapped tube compared to a smooth tube could be as much as 80% for the same temperature drop across the condensate film. The largest enhancements corresponded to a P/D_w ratio of between 5 and 7.

D. OBJECTIVES

The main objectives of this thesis were:

1. To find an accurate inside heat-transfer correlation, which is not sensitive to the Reynolds number exponent, for use in the data reduction technique.

2. To manufacture and collect condensation data on a series of titanium wire-wrapped smooth and roped tubes.

3. To check the repeatability of results of past researchers on the enhancement in the outside heat transfer coefficient due to wire-wrapping a copper tube.

4. To determine any effect of wire pitch and wire diameter on the enhancement in the outside heat transfer coefficient as compared to a smooth tube.

II.   LITERATURE SURVEY

A.   INTRODUCTION

When filmwise condensation occurs on a smooth horizontal tube, a thin condensate film forms around the tube. This condensate film provides a resistance to the heat transfer across the tube, so if the thickness of the film can be reduced, then the heat transfer rate will increase. To reduce the thickness of the film, several different methods have been used including low integral fins, wire-wrapped, and roped tubes. In the past, it was thought that enhancing a tube in this way for steam condensation would be impractical because the high surface tension would cause condensate to be retained between the surface enhancement on the tube, degrading performance.

The Naval Postgraduate School has conducted extensive research in enhancing the heat transfer performance of condenser tubes. The direction of the experimental research recently has been to find the optimum tube for condensation using the various enhancement methods.

B.   FILM CONDENSATION OF STEAM ON A SMOOTH TUBE

In 1916, Nusselt [Ref. 10] showed that for a quiescent vapor condensing on a horizontal tube, the thickness of the condensate film varied around the tube. This variation led to

a variation in the local heat transfer coefficient, being a maximum at the top of the tube where the film is the thinnest. Nusselt's theoretical result for the mean heat transfer coefficient of a pure saturated vapor on a horizontal cylinder was:

$$h_o = 0.728 \left[\frac{k_f^3 \, \rho_f (\rho_f - \rho_v) \, g \, h_{fg}}{\mu_f \, D_o \, \Delta T_f} \right]^{1/4} \tag{2.1}$$

Nusselt's equation has been verified experimentally for a stationary vapor surrounding the tube. However, in most steam surface condensers, the vapor is moving with some velocity. The velocity of the vapor affects the thickness of the condensate film due to the drag imparted on it by the vapor. Shekriladze and Gomelauri (1966) [Ref. 11] took this surface shear into account and derived the following theoretical equation for the mean Nusselt number (dimensionless mean heat transfer coefficient):

$$\frac{Nu}{Re_{2\theta}^{1/2}} = 0.64 \, (1 + (1 + 1.69 F^*)^{1/2})^{1/2} \tag{2.2}$$

where:

$$F^* = \frac{Pr}{Fr \, Ph} = \frac{g \, D_o \, \mu_f \, h_{fg}}{U_\infty^2 \, k_f \, \Delta T_f} \tag{2.3}$$

$$Re_{2\theta} = \frac{\rho_f \, U_\infty \, D_o}{\mu_f} = two \ phase \ Reynolds \ number$$

F* is a dimensionless parameter which relates the gravity force to the shear force. At high values of F*, where gravitational forces dominate, equation (2.2) reduces to the Nusselt equation shown in equation (2.1). A low values of F*, equation (2.2) predicts significantly higher values of h_o than equation (2.1) due to the action of the vapor shear forces thinning the condensate film.

Fujii et al [Ref. 12], in 1979, formed an empirical correlation for the vapor side Nusselt number from forced convection steam condensation data:

$$\frac{Nu}{Re_{2\theta}^{1/2}} = 0.96\,F^{*\,1/5} \tag{2.4}$$

Again, at high values of F*, equation (2.4) gives the same result as equation (2.1).

In a situation where surface shear forces are significant for steam condensation, equation (2.4) seems to be the most accurate. The reader is referred to Rose [Ref. 13] for further reading on the topic of filmwise condensation on a smooth horizontal cylinder.

C. FILM CONDENSATION ON WIRE WRAPPED TUBES

The technique of wrapping a wire around a smooth tube to enhance performance was first introduced by Thomas [Ref. 14] in 1967 for vertical tubes. He judged that the wire, creates a low pressure region at the base of the wire due to the small

radius of curvature. This low pressure region draws in condensate from between the wires (where the pressure is greater), thinning the condensate film and improving the outside heat transfer coefficient.

The same explanation can be used to explain why enhancement occurs for a horizontal wire-wrapped horizontal tube. Figure 1 is an idealized profile of a wire wrapped tube. The low pressure region forms at the base of the wire with the higher pressure region forms between the wires. The amount of heat transferred through the wire is usually negligible compared to the rest of the surface. This is not only because of the high thermal contact resistance between the tube and the wire but also because the thicker condensate layer that is formed at the base of the wire tends to inhibit heat transfer in this region.

1. Summary of Wire-Wrap Tube Research

Previous researchers have found that wire-wrapped smooth tubes can lead to significant enhancement over plain smooth tubes. Sethumadhavan and Rao [Ref. 15] used single wire-wrapped horizontal tubes in a steam condenser with negligible vapor shear and showed that the tubes had an outside heat transfer coefficient enhancement of between 10% and 45% over plain smooth tubes; unfortunately, the material of the tube was not specified. They used three different wire diameters, 0.71 mm, 1.5 mm, and 3.0 mm. The maximum

Figure 1.   Idealized Condensate Film Profile on a Wire-Wrapped Tube

enhancement   of 45% was obtained for the 3.0 mm wire at a pitch of 15 mm, giving a $P/D_w = 5$.   The fractional coverage by the wire of the tube, F, in this case corresponded to 21%. They were trying to determine if there was a relationship between either F or P/D_w and the heat transfer enhancement such that the performance of wire-wrapped smooth tubes could be predicted.

The   same   year   Fujii   et al.   [Ref.   16]   presented data condensing R-11 and ethanol on a single wire-wrapped smooth tube.   Wire diameters of 0.1 mm, 0.2 mm, and 0.3 mm were used on copper tubes.   They showed an increase in the outside heat transfer coefficient of 2 to 3 times that predicted by the

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Nusselt equation for a smooth tube. This maximum enhancement of the outside heat transfer coefficient occurred at P/D_w of 2. They also modeled the relationship between P/D_w and the outside heat transfer coefficient enhancement and found reasonable agreement with their data.

Marto et al. [Ref. 17] showed enhancements in the outside heat transfer coefficient of up to 80% for a single wire-wrapped smooth copper tube over a plain smooth copper tube condensing steam (i.e. significantly lower than that found by Fujii [Ref. 16] for R-11). Their results showed an optimum P/D_w between 5 and 7. Titanium wire diameters of 0.5 mm, 1.0 mm, and 1.6 mm were used, the difference in the results for R-11 and steam is the condensate retention between the wires for the case of steam. They then improved the model of Fujii et al. [Ref. 16] to account for the condensate retention and obtained reasonable agreement with there data.

Marto and Wanniarachchi [Ref. 19] tested smooth and roped titanium tubes, both with and without wire-wrap using steam in a tube bundle that could simulate up to 30 tubes in a vertical column. For the wire-wrapped tubes, a wire diameter of 1.6 mm was used. They reported that the mean bundle outside heat transfer coefficient could be significantly increased by using wire-wrapped tubes. Due to the fact that they are much less susceptible to the effects of condensate inundation.

D. FILM CONDENSATION ON ROPED TUBES

Roped tubes lower the overall thermal resistance in several ways; first by promoting turbulent flow on the coolant side disrupting the laminar sublayer. Secondly, the rounded geometry and grooves on the outside surface of the tube set up low pressure regions which thin the condensate film over much of the tube's outer surface area (Figure 2). The grooves in the roped tube also make it easier for the condensate to drain off the tube. By thinning the film over most of the tube surface, the outside heat-transfer is enhanced.

The disadvantage of roped tubes is that the tubeside pressure drop is increased, so more pumping capacity is needed to provide the same coolant flow rate as with a smooth tube. The magnitude of this increased pressure drop is related to the groove depth and pitch. There is therefore always a trade-off between the increased heat transfer and the increased pressure drop, which can only be sorted out from an economic standpoint.

1. Summary of Roped Tube Condensation Data

In 1971, Withers and Young [Ref. 19] evaluated the use of roped tubes in a distillation plant condenser. They obtained enhancements of up to 50% in the overall heat transfer coefficient using the roped tubes with an equal pressure drop across the coolant side of the condenser. Catchpole and Drew [Ref. 20] tested various single roped

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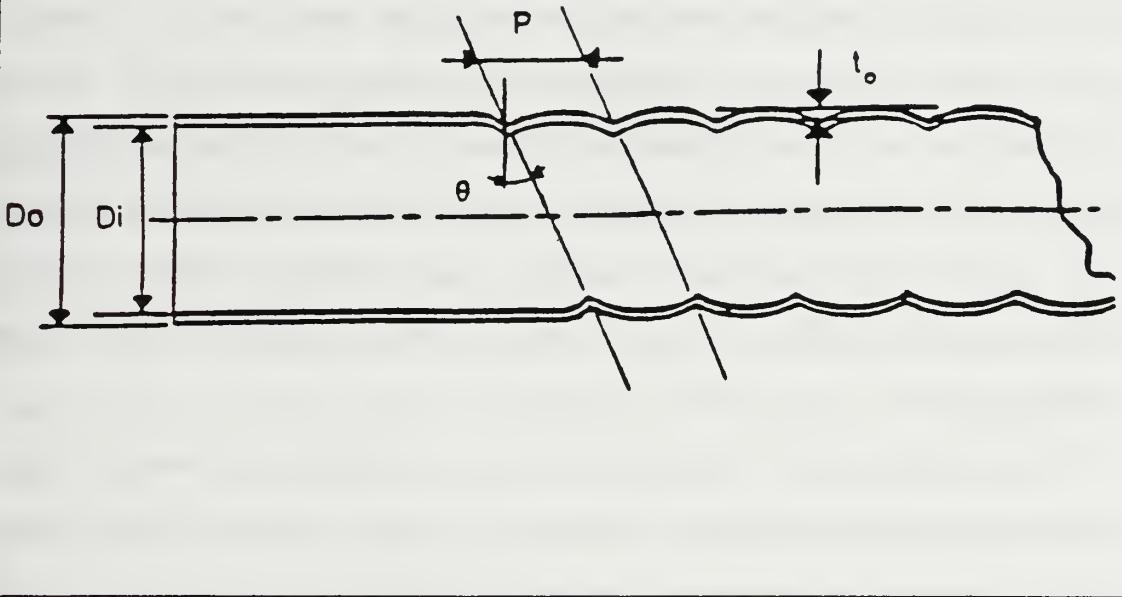
Figure 2. Profile of a Roped Tube

tubes. They varied the pitch and groove depth in the tubes and also obtained overall heat transfer improvements of up to 50%. There was always an enhancement with the roped tubes; the optimum tube for use, based on single tube data only, depended on a balance between space and weight requirements and higher operating cost due to the increased pumping power required.

Mehta and Rao [Ref. 21] tested roped aluminum tubes and were able to show that the outside heat transfer coefficient was enhanced between 16% and 38%, as compared to Nusselt theory for a smooth aluminum tube. Marto, Reilly, and Fenner [Ref. 22] tested eleven different roped tube configurations

(i.e. varying the groove pitch and depth) made of various materials. The tube was set up in a bundle arrangement to simulate a portion of a steam condenser. They found that the outside heat transfer coefficients, when compared to a smooth tube, were enhanced from 0.85 to 1.34 for the various tubes. The tubes with the highest performance had the deeper grooves and, as a consequence, larger coolantside pressure drops. They also noted that if the high performance tubes were not supported properly, there could be problems with tube vibration.

Cunningham et al. [Ref. 23, 24] studied the use of roped tube bundles in a steam condenser. They looked at two roped tubes with the same groove depth and pitch except one tube had six helical starts and the other tube had two helical starts. Their results showed that the roped tubes increased the overall heat transfer coefficient by 20% for the six start tube and up to 50% for the two start tube. The two start tubes showed higher performance for the top tube in the bundle, but lower tubes had problems with inundation. For the six start tubes, inundation did not have as large an effect as with the two start tubes, probably due to the better drainage. The six start tubes would therefore give the best overall performance when operating in a bundle.

In 1980, the Tennessee Valley authority retubed their Gallatin Steam plant Unit I condenser with 90-10 Cu-Ni LPD roped tubes and obtained an increase between 38% and 43% in

the overall bundle heat transfer coefficient, as compared to the original smooth tube bundle. However, the overall bundle heat transfer coefficient dropped as the tubes became fouled over a 2 to 4 month period. The fouling was removed by driving a stiff bristle brush through the tubes with high pressure air and water. After the fouling was removed, a 47% increase in the overall bundle heat transfer coefficient. (as compared to a smooth tube bundle) was observed [Ref. 3]. Mussalli and Gordon [Ref. 25] give a good review of the use of roped tubes in power plant condenser operations. Their paper points out that studies have shown the biofouling rate in smooth and roped tubes is approximately the same for the same water velocity. They also say that the tube enhancement may inhibit fouling buildup beyond a certain thickness due to the increased turbulence of the flow at the wall surface and that the use of chlorination treatment was effective at controlling biofouling in titanium tubes.

In summary, previous research conducted using wire-wrapped smooth and roped tubes in bundles have shown that the effects of condensate inundation can be significantly reduced. This thesis research has been conducted with a view to analyzing the enhancements in the outside heat transfer coefficient of wire-wrapped smooth and roped tubes and to determine if there is a relationship (with an optimum) between P/D_w or F to the heat transfer enhancement.

III. APPARATUS AND SYSTEM INSTRUMENTATION

A. SYSTEM OVERVIEW

The apparatus used is the same as that used by Swensen [Ref. 5]. A schematic of the overall system is shown in Figure 3. Steam is generated from distilled water using ten 4 kW, 440 Volt Watlow immersion heaters in a 0.30m diameter Pyrex boiler. The steam passes from the boiler section up through a 2.13m (ID of 0.15m) straight length of Pyrex glass piping. It is then redirected 180 degrees by two 90 degree Pyrex glass elbows, and flows 1.52m down a straight length of Pyrex tubing into the stainless steel test section. The stainless steel test section contains the horizontally mounted condenser tube as shown in Figures 3 and 4. A circular viewing port in the test section allows the condensation process to be observed during testing. Any excess steam passes through the test section and into the auxiliary condenser unit. The auxiliary condenser is constructed of a single copper coil mounted to a stainless steel base at the bottom of a Pyrex glass condenser section. The condensed water is then returned to the boiler section by a gravity drain in the baseplate of the auxiliary condenser.

The auxiliary condenser is cooled by a continuous supply of tap water controlled by a throttle valve and flow meter.
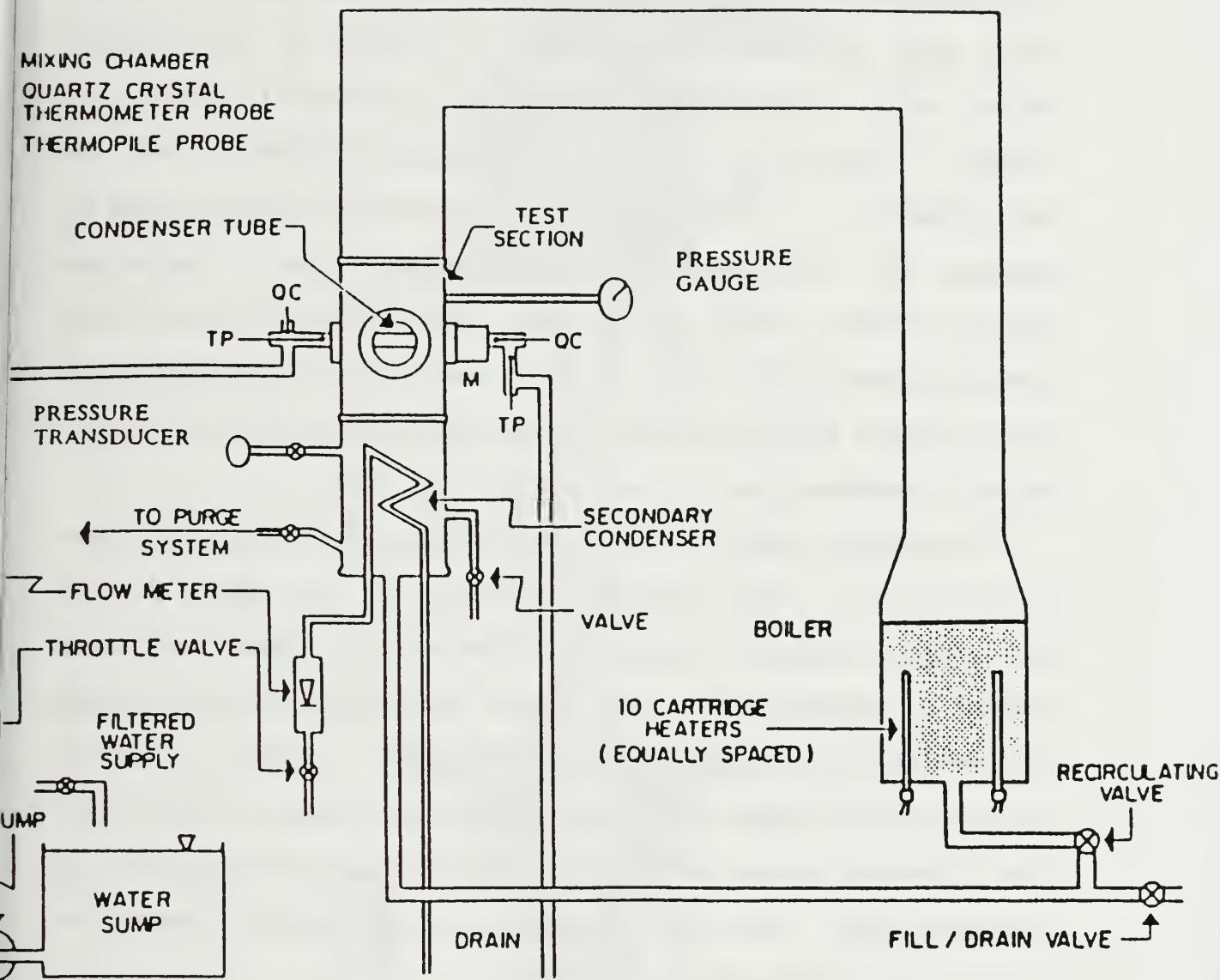
Figure 3. Schematic of the Single Tube Test Apparatus

Cooling water for the single horizontal tube is provided by a coolant system. This closed loop system consisted of a water sump tank, two centrifugal pumps in series, a flow control valve, and a calibrated flow meter as shown in Figure 3. Figure 4 shows the details of the test section and the arrangement of all the temperature measuring devices used to measure the temperature rise across the tube. The nylon mixing chamber mixes the flow at the outlet to ensure the average temperature of the flow is measured. The coolant flow rate through the horizontal tube can be varied to adjust the rate of condensation on the single test tube.

The system used to remove non-condensible gases is shown in Figure 5. The suction point is at the base of the auxiliary condenser where non-condensible gases are most likely to accumulate. The vacuum pump draws the air/steam mixture through an external condensing coil, which is located in the coolant sump tank, to condense any steam in the line. The condensed steam collects in a plexiglas container and is drained later. The air and other non-condensible gases are expelled to the atmosphere.

B. SYSTEM INSTRUMENTATION

The electrical power input to the 440 V_{AC} immersion heaters was controlled by a panel mounted potentiometer. The power calculation for the data acquisition system is described in detail by Poole [Ref. 26]. System pressure was monitored by
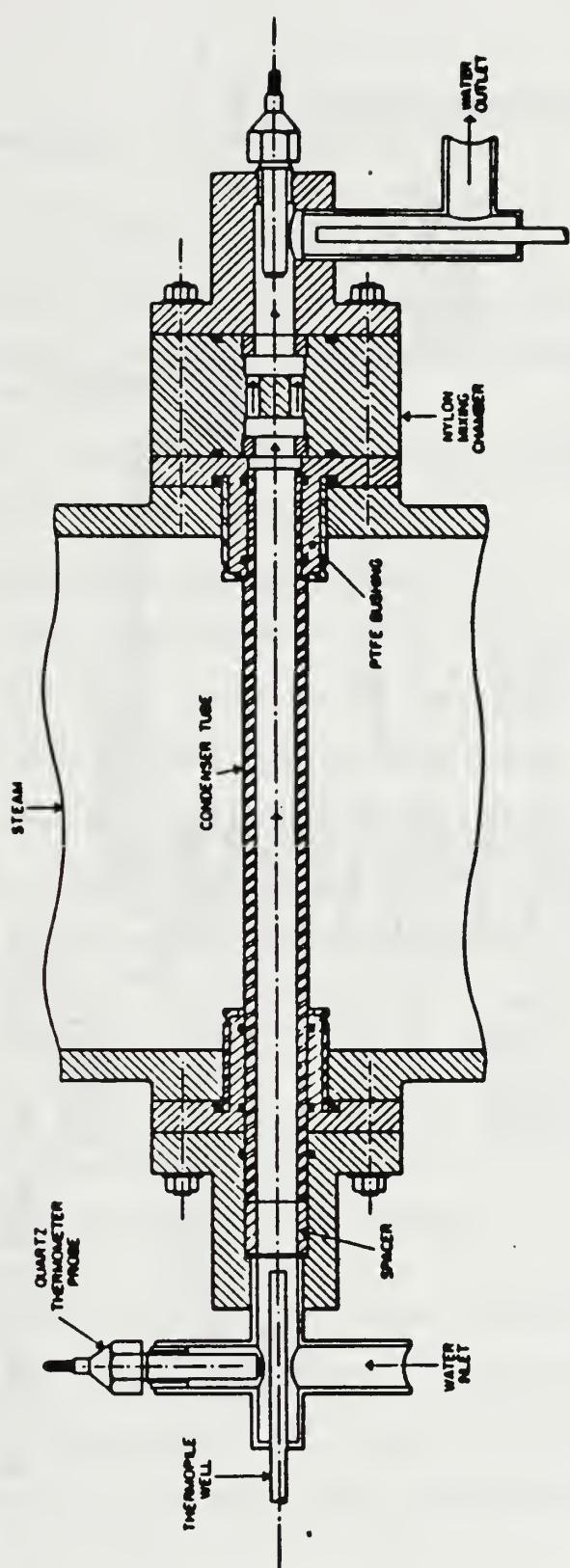
Figure 4. Schematic of the Test Section Insert

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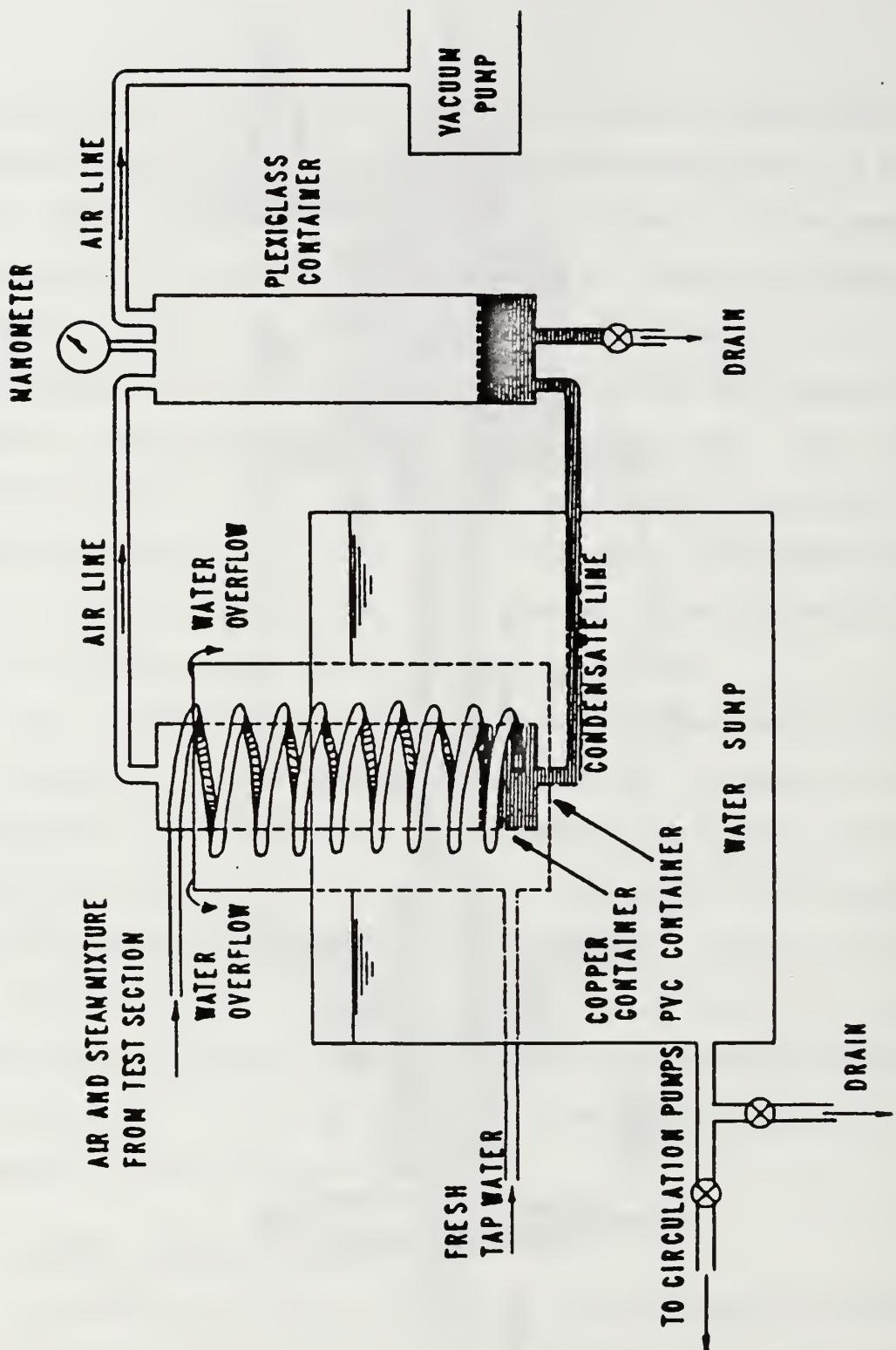
Figure 5. Schematic of Purging System and Cooling Water Sump

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three different methods:

1. Setra model 204 pressure transducer.

2. System saturation temperature converted into pressure.

3. Heise solid front pressure gage (visual reading only).

The calibration for the pressure transducer and temperature instruments is given in Swensen [Ref. 5].

The system vapor temperature was measured by both a Teflon coated and a metal sheathed type-T copper/constantan thermocouple located just upstream of the test tube. The condensate return and ambient surrounding temperatures were measured with Teflon coated type-T copper/constantan thermocouples. The temperature rise of the coolant in the tube being tested was measured by three separate methods:

1. A single Teflon coated type-T copper/constantan thermocouple.

2. A ten-junction Teflon coated type-T copper/constantan thermopile.

3. An HP 2804A quartz crystal thermometer.

The relative positions of each of these three temperature measuring methods are shown in Figure 4. At the outlet of the tube, the coolant temperature is always measured after a coolant mixing chamber to ensure a well averaged temperature measurement.

All the data from the system instrumentation were processed using an HP-3497A data acquisition system controlled

by an HP-9826A computer. The raw data were processed and stored on computer disks. The data could then be reprocessed using a modified Wilson plot technique to obtain an outside heat-transfer coefficient (see section IV.C for details).

C. TUBES TESTED

There were twelve tubes fabricated for this thesis. Some of the wire-wrapped smooth tubes were the same as used by Brower [Ref. 8], except they were altered to fit into the single tube apparatus used during this thesis. Listed in Table I are all the tubes that were tested and their associated dimensions. The tubes consisted of one smooth tube and seven wire-wrapped smooth tubes, all made of titanium. Three different wire diameters were used at various spacings on the tube, providing a range of wire pitch to wire diameter between 2 and 10. These are also listed in Table I. Commercially available titanium roped tubes (Wolverine KORODENSE LPD) were also tested, both with and without the three different wire diameters. The wires were placed in the corrugated grooves, giving the wires a fixed pitch. In addition, a smooth copper tube and two of the wire-wrapped copper tubes tested by Mitrou [Ref. 9] were tested (see Table I).

Table I. LISTING OF THE TUBES TESTED

Tube No.	Tube Type	Wire Diameter (mm)	Wire Spacing (mm)	Wire Pitch (mm)	P/D Ratio	F	Outside Diameter (mm)	Inside Diameter (mm)	Tube Material
0	Smooth	None	None	None	None	0	15.85	13.86	Titanium
1	Smooth	1.6	13.47	15.07	9.42	0.108	15.85	13.86	Titanium
2	Smooth	1.6	5.75	7.35	4.59	0.205	15.85	13.86	Titanium
3	Smooth	1.6	1.80	3.40	2.13	0.457	15.85	13.86	Titanium
4	Smooth	1.0	5.04	6.04	6.04	0.158	15.85	13.86	Titanium
5	Smooth	1.0	3.70	4.70	4.70	0.211	15.85	13.86	Titanium
6	Smooth	0.5	3.46	3.96	7.92	0.120	15.85	13.86	Titanium
7	Smooth	0.5	1.51	2.01	4.02	0.218	15.85	13.86	Titanium
L	LPD	None	None	None	None	0	15.85	13.47	Titanium
L1	LPD	1.6	5.40	7.00	4.38	0.252	15.85	13.47	Titanium
L2	LPD	1.0	6.00	7.00	7.00	0.152	15.85	13.47	Titanium
L3	LPD	0.5	6.50	7.00	14.00	0.074	15.85	13.47	Titanium
50	Smooth	None	None	None	None	0	19.05	12.70	Copper
68	Smooth	1.0	3.91	3.91	3.91	0.269	19.05	12.70	Copper
71	Smooth	0.5	3.13	3.63	7.26	0.141	19.05	12.71	Copper

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IV. EXPERIMENTAL PROCEDURES AND DATA REDUCTION

A. EXPERIMENTAL PROCEDURES AND OBSERVATIONS

Titanium and copper both have different wetting characteristics with respect to water. However, to ensure filmwise condensation, both types of tubes have been successfully treated with a sodium hydroxide and ethyl alcohol solution. This treatment has been used by several researchers in the past at NPS. Each tube was prepared in the following manner:

1. Both the inside and outside surfaces of the tube are cleaned using a mild soap and soft bristle brush. The tube is then rinsed first with distilled water, then with acetone, and again with distilled water to ensure there are no impurities on the surface of the tube. The second rinse should wet the entire surface of the tube with no breaks in the film. **NOTE:** the active surface area of the tube should not be handled during this procedure.

2. The tube is then placed over a steam bath.

3. Equal amounts of a 50% by weight sodium hydroxide solution and ethyl alcohol are mixed and kept warm to ensure a watery consistency is maintained.

4. The solution is then applied to the entire surface of the tube with a small brush every 10 minutes for one hour. If the tube has not been previously treated, apply the solution every 5 minutes for 20 minutes. A black oxide layer will form on the copper tubes. A layer forms on the titanium tubes, but they are not discolored.

5. The tube is then removed from the steam bath and rinsed with distilled water to remove the excess alcohol/sodium hydroxide solution. The tube should be held over the steam bath again to ensure that the entire tube surface wets easily as the steam condenses on it. The tube

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should then be installed into the test section immediately afterward. Care should be taken when installing the tube into the test apparatus so the active surface of the tube is not disturbed.

The oxide layer that forms on the tube causes very good wetting characteristics on the surface of the tube. The oxide layer is very thin so it is assumed that it is negligible to the overall thermal resistance of the tube.

When the tube has been installed, the system is started up in accordance with the procedures given in Appendix B. Tests on the tubes were performed with either a HEATEX insert or no insert at all. The system is heated up to the desired operating condition, at either vacuum or atmospheric pressure, as outlined in the start-up procedure. The system needs to be maintained at equilibrium for at least thirty minutes prior to taking any data measurements. This is to ensure that the entire apparatus is warmed up. Data were taken at coolant flow rates (in %) of 80, 70, 60, 50, 40, 30, and 20, and then in steps of 10% back to 80%. Therefore, each point is checked twice at different times in the run to ensure repeatability. Several sample sets of data were evaluated to ensure the temperature difference across the tube, the saturation temperature, and the overall heat transferred were in equilibrium for each particular flow rate before the final data point was recorded. One data set took anywhere from ten to twenty minutes before the system was in equilibrium so a data set could be recorded.

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Swensen [Ref. 5] describes how difficult it is to initiate filmwise condensation on a copper tube under vacuum pressure. To establish good filmwise condensation for a vacuum run, the following should be done:

1. Ensure coolant flow to the tube is secured. Then allow the apparatus vapor temperature (channel 40) to reach 3600-3800 microvolts.

2. Raise the auxiliary condenser flow rate to 50-60%, to cool the vapor temperature to ~3200 microvolts.

3. Secure the flow to the auxiliary condenser, and allow the vapor temperature to rise to 3700 - 3800 microvolts. This forms a steam blanket around the tube.

4. Initiate cooling water flow to the single tube being tested at a flow rate of at least 80%.

5. Restore flow to the auxiliary condenser to control vapor temperature and pressure. Observe the single tube through the viewing window to ensure good filmwise condensation has been established.

6. If some dropwise condensation persists, the steps above can be repeated. If dropwise condensation still continues, the tube should be removed and retreated with the ethyl alcohol and sodium hydroxide solution.

The wettablity of titanium and copper are different. It was much easier to obtain filmwise condensation on the titanium tubes than the copper tubes. Also, it appeared as if it was easier to initiate filmwise condensation on the enhanced tubes than the smooth tubes. Under vacuum conditions (pressures ≈12 kPa) at low cooling water flow rates, small patches of dropwise condensation could be seen on the bottom of the titanium tube at fairly regular intervals. These "dryout" patches appear to be the same as those described by

Swensen [Ref. 5] for the copper tube, and are believed to be caused by vortex shedding of the vapor around the tube. When the coolant flow rate was increased above 40%, there was enough condensate to spread out and cover the tube surface and the "dryout" patches did not occur.

B. DATA REDUCTION PROCEDURES

The overall thermal resistance is represented by the sum of the coolant side resistance (R_i), the wall resistance (R_w), the fouling resistance (R_f), and the vapor side resistance (R_o). Since only clean tubes are used, the fouling resistance is negligible, ($R_f=0$). Therefore,

$$R_{total} = R_i + R_w + R_o \qquad (4.1)$$

The coolant and vapor side resistances are convective in nature, so they need to be related to the areas:

$$R_i = \frac{1}{h_i A_i} \qquad (4.2)$$

$$R_o = \frac{1}{h_o A_o} \qquad (4.3)$$

where:

R_i = inside resistance to heat transfer (K/W)

h_i = inside heat transfer coefficient (W/m^{2}K)

A_i = effective inside heat transfer area (m^2)

R_o = outside resistance to heat transfer (K/W)

h_o = outside heat transfer coefficient (W/m^{2}K)

A_o = effective outside heat transfer area (m²)

The effective area for the inside of the tube is represented by the entire length of the tube. The portions of the tube that are not exposed to steam act as fins, which will remove heat in the axial direction. The extended fin assumption and the associated fin efficiencies are used to account for the inlet and outlet portions of the tube. So, the effective inside area of the tube can be represented as:

$$A_i = \pi D_i (L + L_1 \eta_1 + L_2 \eta_2) \qquad (4.4)$$

where:

D_i = inside diameter of the tube (m)

L = length of tube exposed to steam, active working length (m)

L_1 = length of the inlet portion of the tube (m)

L_2 = length of the outlet portion of the tube (m)

η_1 = fin efficiency of the inlet portion of the tube

η_2 = fin efficiency of the outlet portion of the tube

The effective outside surface area is dependent on the length of the tube exposed to steam, the active condensation length. The effective outside area is represented as:

$$A_o = \pi D_o L \qquad (4.5)$$

The wall resistance assumes uniform radial conduction and is represented by the following equation:

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$$R_w = \frac{\ln\left(\dfrac{D_o}{D_i}\right)}{2\pi L k_m} \qquad (4.6)$$

where:

R_w = tube wall resistance (K/W)

D_o = outside diameter of the tube (m)

D_i = inside diameter of the tube (m)

k_m = thermal conductivity of the wall material (W/mK)

The overall thermal resistance can be related to the overall heat transfer coefficient (U_o) and the effective outside area (A_o) by:

$$R_{total} = \frac{1}{U_o A_o} \qquad (4.7)$$

where:

U_o = overall heat transfer coefficient (W/m²K)

Substituting equations (4.2), (4.3), and (4.7) into (4.1) gives:

$$\frac{1}{U_o A_o} = \frac{1}{h_i A_i} + R_w + \frac{1}{h_o A_o} \qquad (4.8)$$

The total heat transfer rate to the single tube can be calculated from an energy balance by using the temperature difference of the cooling water across the tube and the mass flow rate of the coolant through the tube:

$$Q = \dot{m}C_p(T_2 - T_1) \qquad (4.9)$$

The overall heat transfer coefficient can then be calculated from:

$$Q = U_o A_o (LMTD) \qquad (4.10)$$

where:

$$LMTD = \frac{(T_2 - T_1)}{\ln\left[\dfrac{T_{sat} - T_1}{T_{sat} - T_2}\right]} \qquad (4.11)$$

where:

Q   =   total heat transfer rate (W)

m   =   mass flow rate of the coolant (kg/s)

C_p =   Specific heat of coolant at constant pressure (J/kgK)

LMTD =   log mean temperature difference

T_1 =   inlet coolant temperature (K)

T_2 =   outlet coolant temperature (K)

T_{sat} =   vapor saturation temperature (K)

The inlet and outlet cooling water temperatures were measured with a quartz thermometer and the saturation temperature was measured using the vapor thermocouple (channel 40). In addition, a correction factor was used to account for the viscous heating of the coolant through the tube; there correction equations are shown in Appendix A.

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Once the total heat transfer rate has been calculated, the overall heat transfer coefficient can be calculated by using equation (4.10). Now only two unknowns remain, the inside heat transfer coefficient, h_i, and the outside heat transfer coefficient, h_o. These are computed using the modified Wilson plot technique.

C. MODIFIED WILSON PLOT TECHNIQUE

The most accurate way to obtain inside and outside heat transfer coefficients is to measure the vapor temperature, mean wall temperature, and the coolant temperature directly. The coolant and vapor temperatures can be easily measured. However, to measure the tube wall temperature an, instrumented tube (with thermocouples embedded in the wall) must be used. With the instrumented tube, the inside and outside heat transfer coefficients can be calculated directly. Unfortunately, the manufacturing of instrumented tubes is costly and time consuming. Also, instrumented tubes would be impractical if a large number of tubes are to be tested.

An alternative to using an instrumented tube is to solve for both the outside and inside heat transfer coefficients simultaneously using the modified Wilson plot technique. A detailed outline of the technique is given by Marto [Ref. 27].

The modified Wilson plot technique relies on the fact that the overall heat transfer coefficient can be reliably measured from experimental data. Two forms of equations need to be

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selected for the inside and outside heat transfer coefficients. In this thesis, the outside heat transfer coefficient is represented by the equation of Nusselt [Ref. 10] based on ΔT:

$$h_o = \alpha \left[\frac{k_f^3 \rho_f^2 g h_{fg}}{\mu_f D_o \Delta T_f} \right]^{1/4} = \alpha Z \qquad (4.12)$$

where:

α = dimensionless Nusselt coefficient

k_f = thermal conductivity of the condensate film (W/mK)

ρ_f = density of the condensate film (kg/m³)

μ_f = dynamic viscosity of the condensate film (kg/ms)

h_{fg} = specific enthalpy of vaporization (J/kg)

ΔT_f = temperature difference across the condensate film (K)

g = gravitational constant (9.81 m/s²)

We also had the option of using Fujii's [Ref. 12] correlation, equation (2.4), for the outside heat transfer coefficient in the program used to evaluate the data. The inside heat transfer coefficient can be represented by one of several correlations. The general form for the inside heat transfer coefficient is:

$$h_i = C_i \Omega \qquad (4.13)$$

where Ω varies with the particular correlation used.

Using the Sieder-Tate correlation [Ref. 6]:

$$\Omega = \frac{k_c}{D_i} Re^x Pr^{1/3} \left(\frac{\mu_c}{\mu_w}\right)^{0.14} \qquad (4.14)$$

where x, the exponent to the Reynolds number, can be varied in
the program evaluating the data.

Using the Sleicher-Rouse correlation [Ref. 28]:

$$\Omega = \frac{k_c}{D_i} (5 + 0.015 Re_f^c Pr_w^d) \qquad (4.15)$$

where:

$$c = 0.88 - \frac{0.24}{4 + Pr_w}$$

$$d = \frac{1}{3} + 0.5 e^{-0.6 Pr_w}$$

Using the Petukhov-Popov correlation [Ref. 29]:

$$\Omega = \frac{k_c}{D_i} \left[\frac{\left(\frac{\epsilon}{8}\right) Re\, Pr}{K_1 + K_2 \left(\frac{\epsilon}{8}\right)^{1/2} (Pr^{2/3} - 1)} \right] \qquad (4.16)$$

where:

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$$\varepsilon = [1.82 \log(Re) - 1.64]^{-2}$$

$$K_1 = 1 + 3.4\varepsilon$$

$$K_2 = 11.7 + 1.8\, Pr^{-\frac{1}{3}}$$

Substituting equations (4.12) and (4.13) into equation (4.8) gives the following:

$$\left[\frac{1}{U_o} - R_w A_o\right] Z = \frac{A_o Z}{C_i \Omega A_i} + \frac{1}{\alpha} \qquad (4.17)$$

Letting:

$$Y = \left[\frac{1}{U_o} - R_w A_o\right] Z \qquad (4.18)$$

and

$$X = \frac{A_o Z}{A_i \Omega} \qquad (4.19)$$

a simplified linear equation results:

$$Y = mX + b \qquad (4.20)$$

where

$$m = \frac{1}{C_i} \qquad (4.21)$$

and

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$$b = \frac{1}{\alpha} \qquad (4.22)$$

the parameters Ω and Z are temperature dependent, so an iterative procedure must be used to solve the equation. A least squares fit of equation (4.17) is used to determine C_i and α. The inside heat transfer coefficient can then be determined using equation (4.13). Since h_i and U_o are both known, the outside heat transfer coefficient can be solved using equation (4.8).

It should be noted that the accuracy of the modified Wilson plot technique is dependent on the number of data points evaluated, as well as the range of flow rates used. The current computer system does not allow different run files to be combined to evaluate a tube. Each file has to be processed separately. This leads to scatter between the data runs for the values of α and C_i between runs for the same types of tube.

D. ENHANCEMENT RATIO

From Nusselt theory, it can be shown that:

$$q = a \, \Delta T_f^n \qquad (4.23)$$

where:

$$a = \alpha \left[\frac{k_f^3 \, \rho_f^2 \, g \, h_{fg}}{\mu_f D_o} \right]^{1/4}$$

q = the heat flux based on the outside area (W/m²)

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ΔT_f= the temperature drop across the condensate film (K)

We also know that the heat flux can be represented by:

$$q = h_o \Delta T_f \qquad (4.24)$$

So, the outside heat transfer coefficient can be represented by:

$$h_o = a \Delta T_f^{n-1} \qquad (4.25)$$

From Nusselt theory, n = 0.75, so the enhancement ratio, based on a constant temperature drop across the condensate film, can be expressed as:

$$E_T = \frac{h_{oe}}{h_{os}} = \frac{a_e}{a_s} = \frac{\alpha_e}{\alpha_s} \qquad (4.26)$$

where the subscripts of e and s refer to enhanced and smooth tubes respectively.

V. RESULTS AND DISCUSSION

A. INSIDE HEAT TRANSFER CORRELATION

Previous to this thesis, Swensen [Ref. 5] gave a discussion of how the inside heat transfer coefficient has been found at NPS. He used an instrumented tube to collect data at atmospheric pressure and empirically derived two variants of the Sieder-Tate correlation to express the inside heat transfer coefficient for a medium size copper tube (D_i = 12.7 mm). These correlations were represented as:

Using a HEATEX insert:

$$Nu = 0.22 \, Re^{0.69} \, Pr^{1/3} \left(\frac{\mu_c}{\mu_w} \right)^{0.14} \qquad (5.1)$$

Using No insert:

$$Nu = 0.013 \, Re^{0.89} \, Pr^{1/3} \left(\frac{\mu_c}{\mu_w} \right)^{0.14} \qquad (5.2)$$

Swensen developed the new correlations because it was thought that the inlet arrangement (a 90 degree bend just prior to the inlet of the tube) was affecting the correlation used to solve for the outside heat transfer coefficient. Almost all of Swensen's data were taken at atmospheric pressure using a HEATEX insert. When this thesis effort started, equations (5.1) and (5.2) were used to evaluate the inside heat transfer

coefficient. These two new correlations should provide comparable results for the outside heat transfer coefficient to those obtained by Swensen [Ref. 5]. The tubes studied in this thesis have a different inside diameter (13.86 mm) and are made from titanium and not copper.

Figures 6 and 7 show the values of the outside heat transfer coefficient for both the titanium and copper tubes at atmospheric and vacuum pressures using equations (5.1) and (5.2) in the data reduction scheme. At atmospheric pressure, Figure 6 shows Swensen's equations work well for the copper tubes; however, the results for the titanium tubes do not agree with Swensen's data well at all. In fact, a reduction of the outside heat transfer coefficient is shown for the HEATEX insert data as the temperature difference across the condensate film decreases, which is contrary to what was expected. At vacuum pressure, Swensen's equations show that the outside heat transfer coefficient curve is flatter than what is given by the instrumented copper tube data; also, the data shows much more scatter. There are several reasons this may have occurred. The first is that the leading coefficients for both correlations are fixed, so a change in the geometry (diameter) may have affected the results using these correlations. Consequently, the leading coefficient was left to 'float' to try and account for these differences. When the data were then reprocessed, the coefficient dropped by 30% for the HEATEX insert data. This drop in the leading coefficient
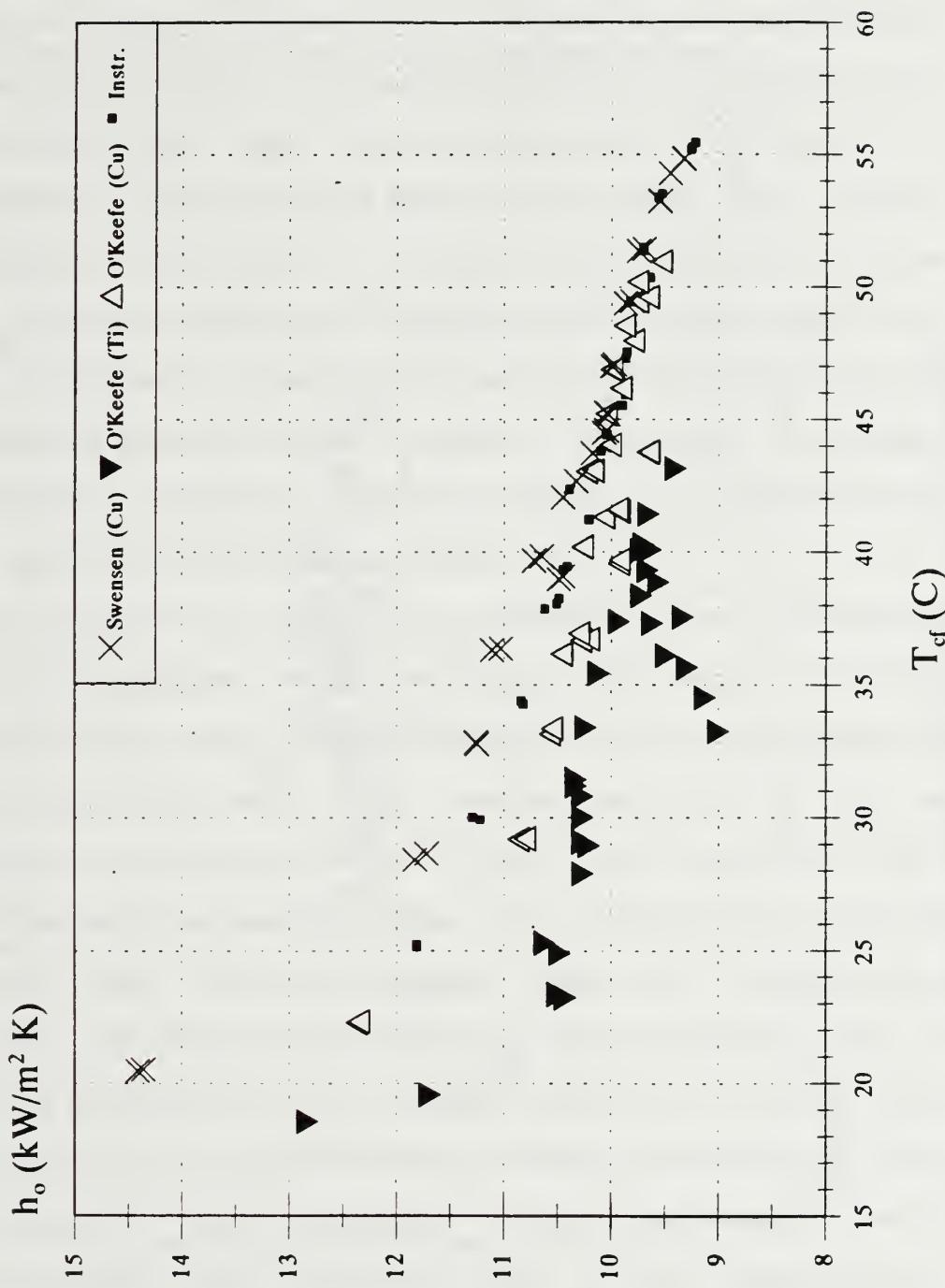
Figure 6. Comparison of Results for the Outside Heat Transfer Coefficient at Atmospheric Pressure Using the Swensen Correlations

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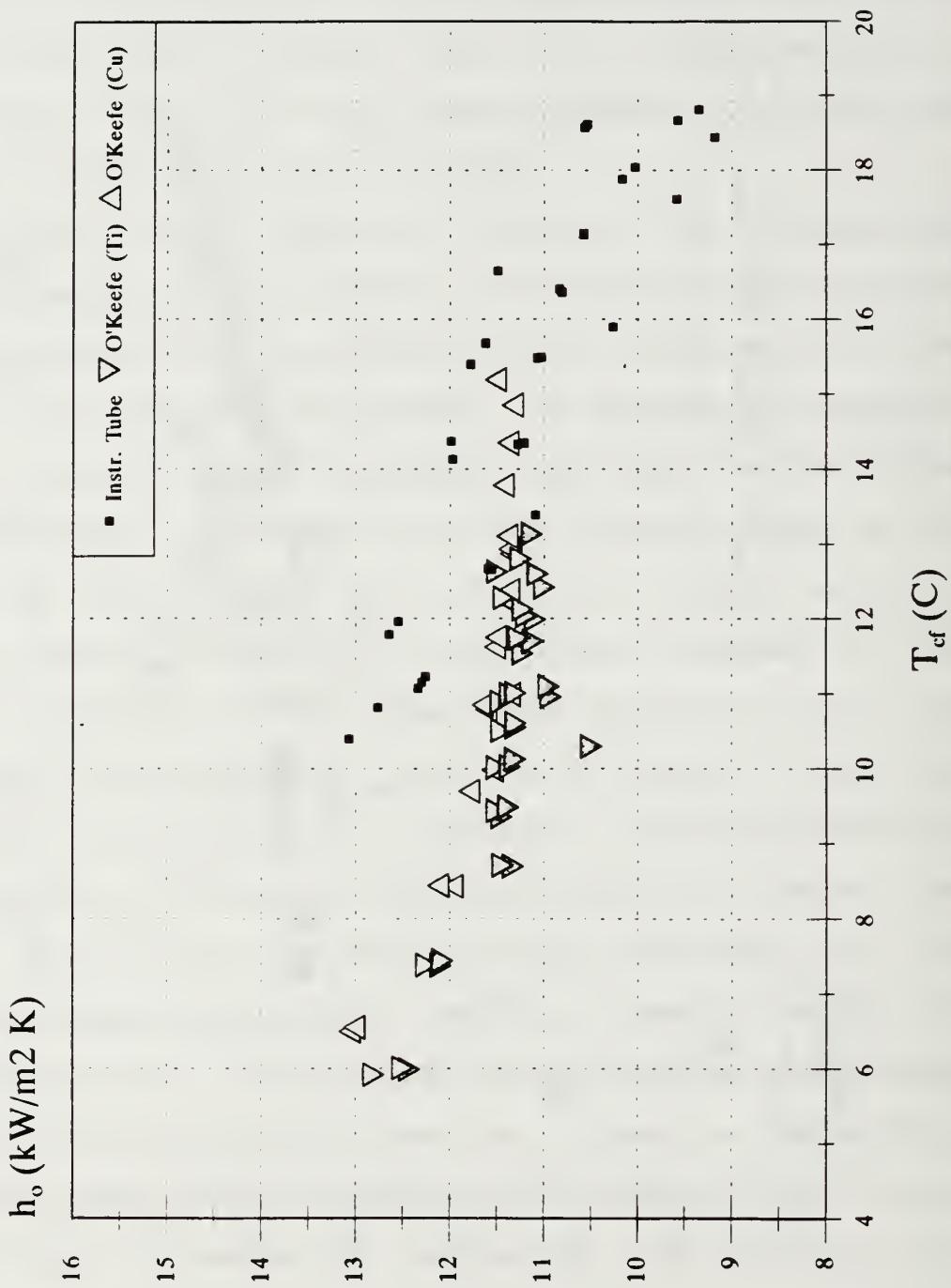
Figure 7. Comparison of the Outside Heat Transfer Coefficients
at Vacuum Pressure using the Swensen Correlations

was much larger than expected, bringing into question the validity of Swensen's correlations for the titanium tube data. The other significant difference between the titanium tube data and the copper tube data is the range of ΔT_f, which is much lower for the titanium tube. The copper tube with the HEATEX insert had higher ΔT_f values for similar coolant flow rates. Swensen produced his correlations for the range of ΔT_f covered by his data. They do not seem to perform well outside this range as seen in Figures 6 and 7. Therefore, it appears as if the data reduction scheme recommended by Swensen should not be used for the titanium tubes.

In an effort to correct the problem, other inside heat transfer correlations were considered. The Argonne National Laboratory (ANL) [Ref. 31] conducted a thorough assessment of several different inside heat transfer correlations for low temperature turbulent water flows to determine which correlation was the most accurate. The conclusions of the ANL study were that the Petukhov-Popov [Ref. 30] and Sleicher-Rouse [Ref. 29] correlations were the most accurate ($\pm$ 5%) in predicting the inside heat transfer coefficient, over a range of Pr=6.0 to 11.6. Both the Petukhov-Popov and Sleicher-Rouse correlations are given in Chapter IV.C and are based on having a long straight inlet section prior to the test section. Swensen identified these correlations as the most accurate but he felt that he could not use them because of the sharp bend

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in the inlet flow arrangement for the test apparatus as previously mentioned.

Both Petukhov-Popov and Sleicher-Rouse correlations were then used except that a floating leading coefficient was inserted to account for the different inlet to the test section, as shown in equations (4.13), (4.15), and (4.16). Figure 8 presents the same data shown in Figure 6 for atmospheric pressure, except they have been reprocessed using the Petukhov-Popov correlation for the inside heat transfer coefficient. It can be seen that the agreement between the titanium and copper tubes is much better in this case. Furthermore, the agreement with the instrumented tube data is much better, consistently within ± 7%. Uncertainty bands are shown on this figure, and the scatter is well within the predicted uncertainty. In the same way, Figure 9 shows the same data as in Figure 7 at vacuum pressure, except the data have been reprocessed using the Petukhov-Popov correlation for the inside heat transfer coefficient. Again the results show that the titanium and copper tube data compare much better with the instrumented tube data. Again the scatter is within the uncertainty of the data. Figure 10 compares the use of the Petukhov-Popov and Sleicher-Rouse correlations and it shows similar results are obtained when the Sleicher-Rouse correlation is used in evaluating the inside heat transfer coefficient. The ANL [Ref. 31] paper said:

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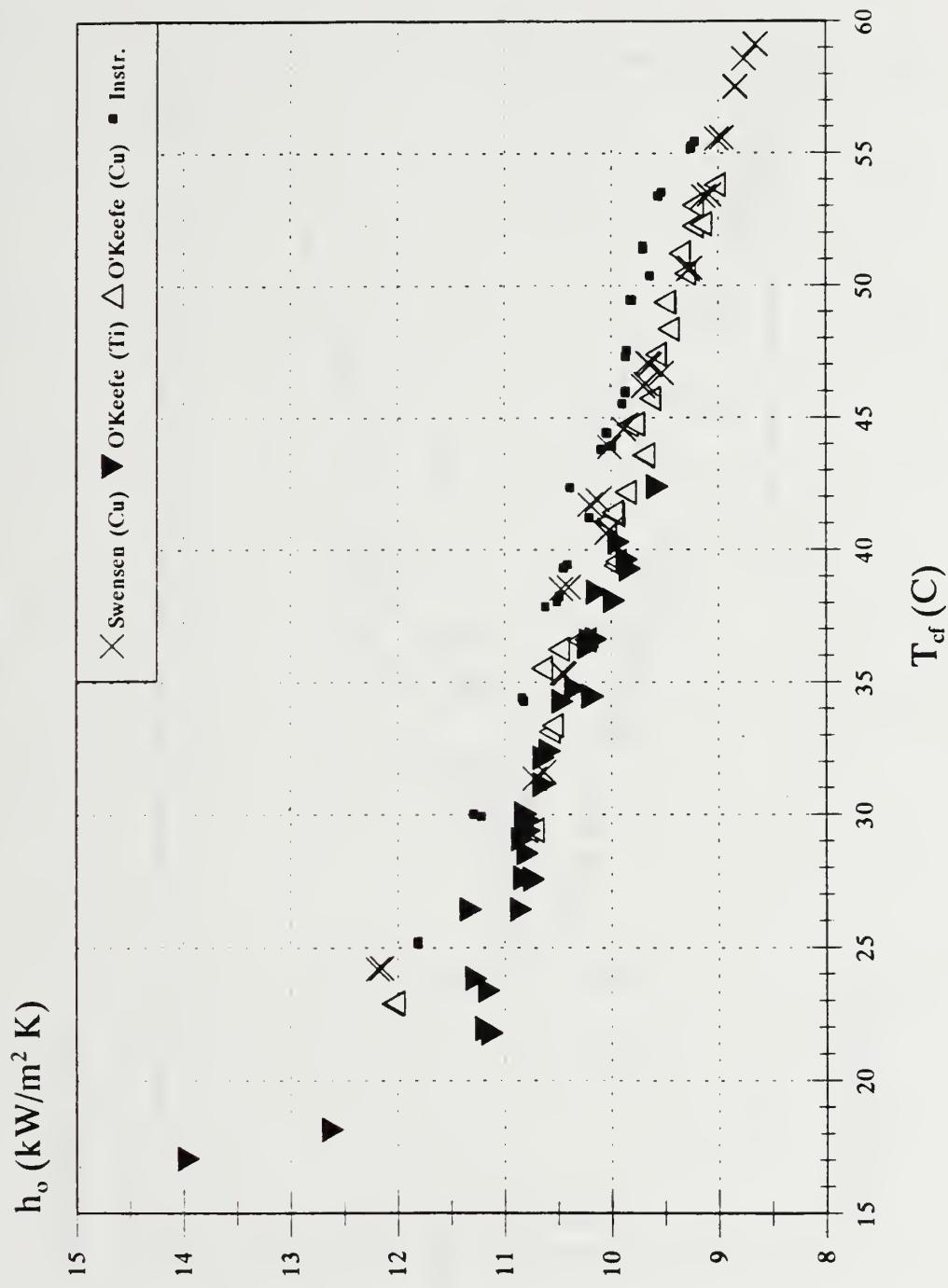
Figure 8. Comparison of the Outside Heat Transfer Coefficients at Atmospheric Pressure using the Petukhov-Popov Correlation
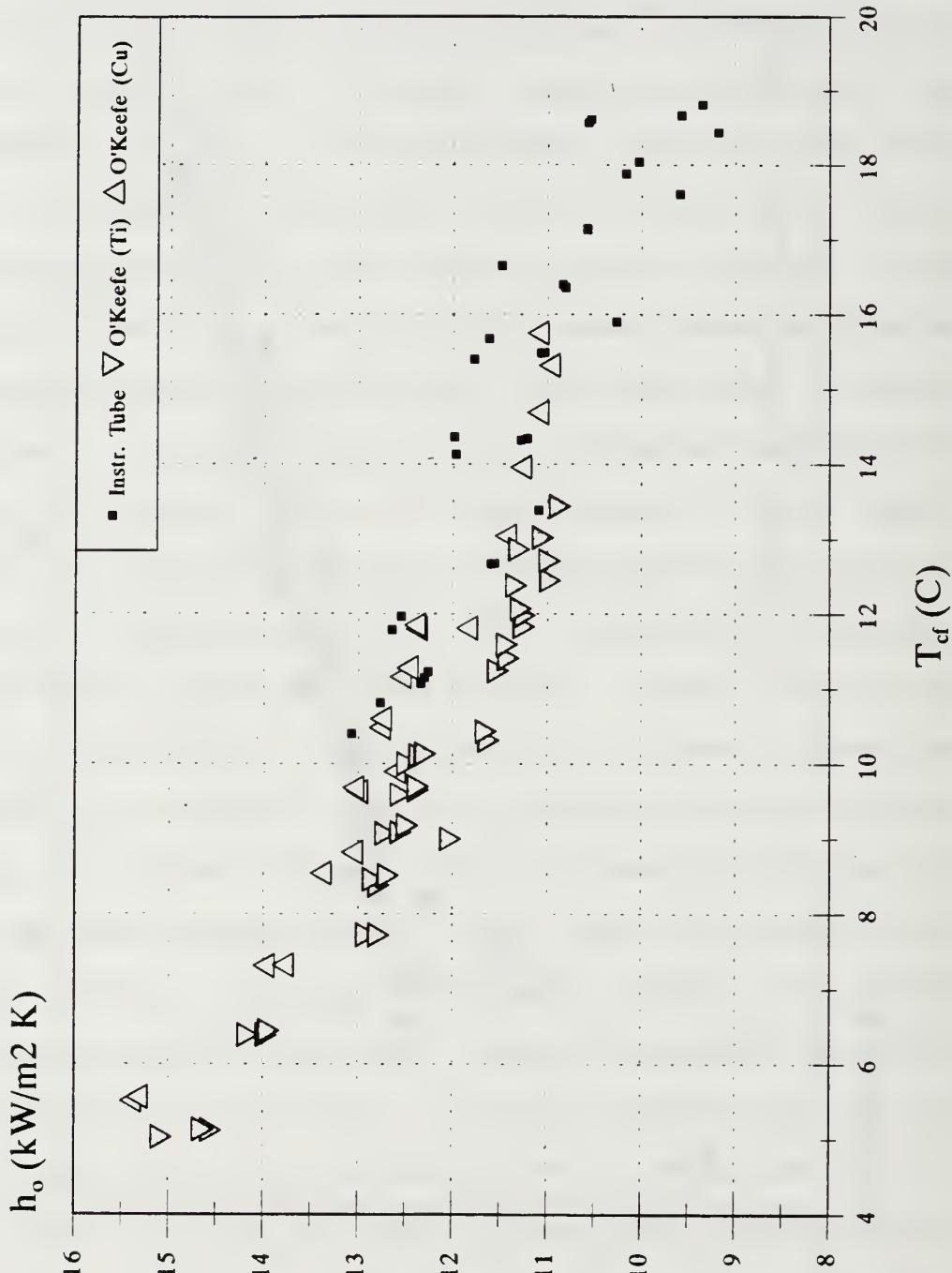
Figure 9. Comparison of the Outside Heat Transfer Coefficients
at Vacuum Pressure Using the Petukhov-Popov Correlation

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h$_o$ vs. T$_{cf}$

Atmospheric Pressure Comparison of Petukhov-Popov and Sleicher-Rouse
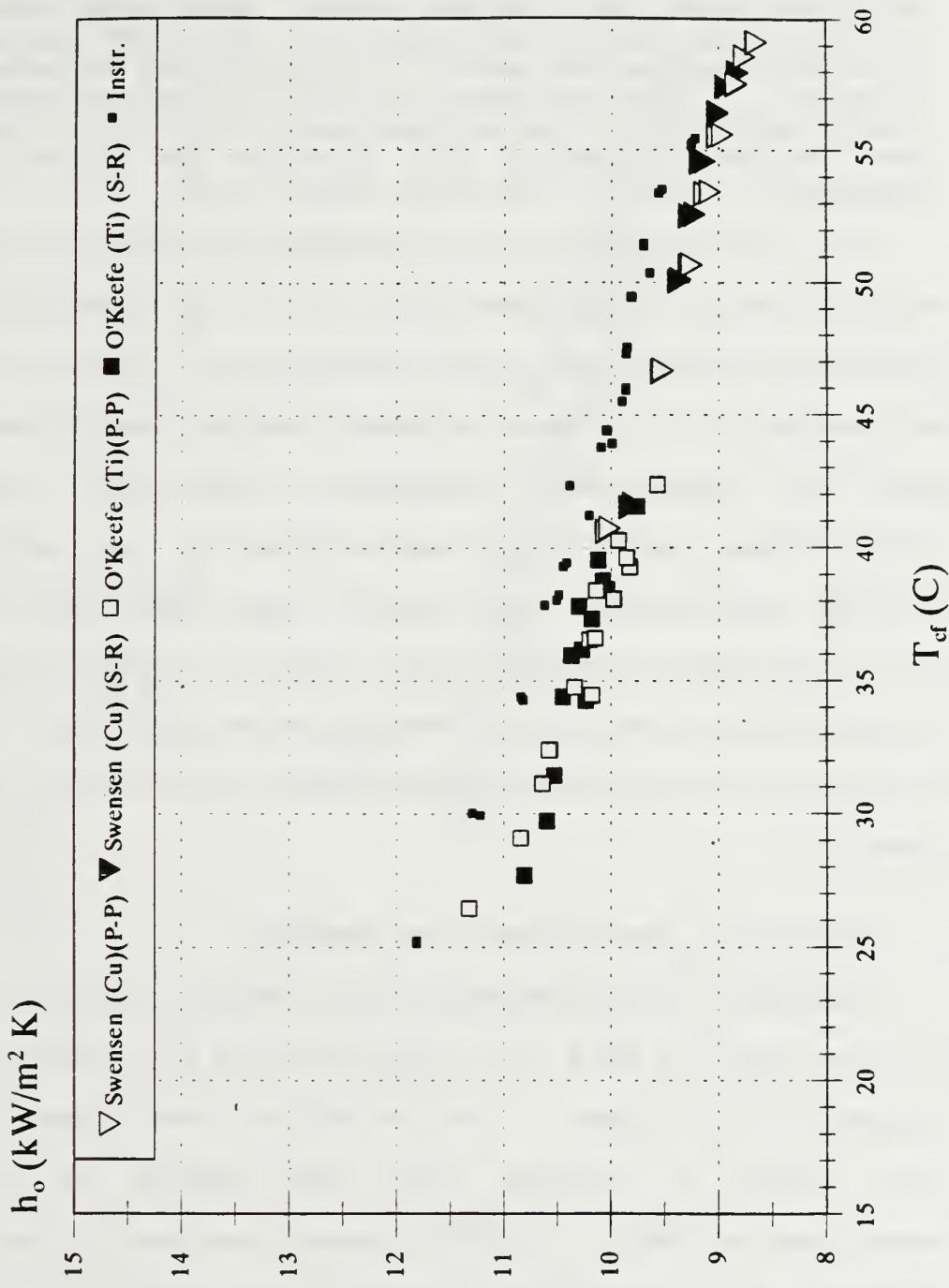
Figure 10.   Comparison if the Inside Heat Transfer
Coefficients using the Petukhov-Popov and Sleicher-Rouse
Correlations

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It is tempting to follow the "old technology" and utilize n = 0.80 as the Reynolds number exponent, in accordance with the popular Dittus-Boelter and Sieder-Tate correlations. However, more recent correlations, such as Petukhov-Popov and Sleicher-Rouse, have been shown to exhibit much better agreement with the most carefully obtained experimental data ... In the Pr and Re ranges of interest ... these correlations yield "effective" Reynolds number exponents in the neighborhood of n = 0.85. Thus it was decided to employ n = 0.85 in the Wilson plot procedure to generate nominal values of h_i.

With this information, the Sieder-Tate equation was then evaluated using an exponent of 0.85 for the Reynolds number and again floating the leading coefficient. Figure 11 shows the results for the outside heat transfer coefficient when using the Sieder-Tate correlation (with $Re^{0.85}$) and the Petukhov-Popov correlation for determining the inside heat transfer coefficient. The results show that there is very little difference between using these two quite different correlations for the inside heat transfer coefficient, giving confidence in the data reduction technique for the titanium tubes.

B. ANALYSIS OF THE SMOOTH TUBE RESULTS

A series of runs were made using a smooth titanium tube to get some baseline data for comparison with the enhanced wire-wrapped titanium tubes. A smooth medium sized copper tube was also tested to compare with the results of previous researchers at NPS. A HEATEX insert was used to boost the values of the inside heat transfer coefficient and thereby improve the measured accuracy of the outside heat transfer

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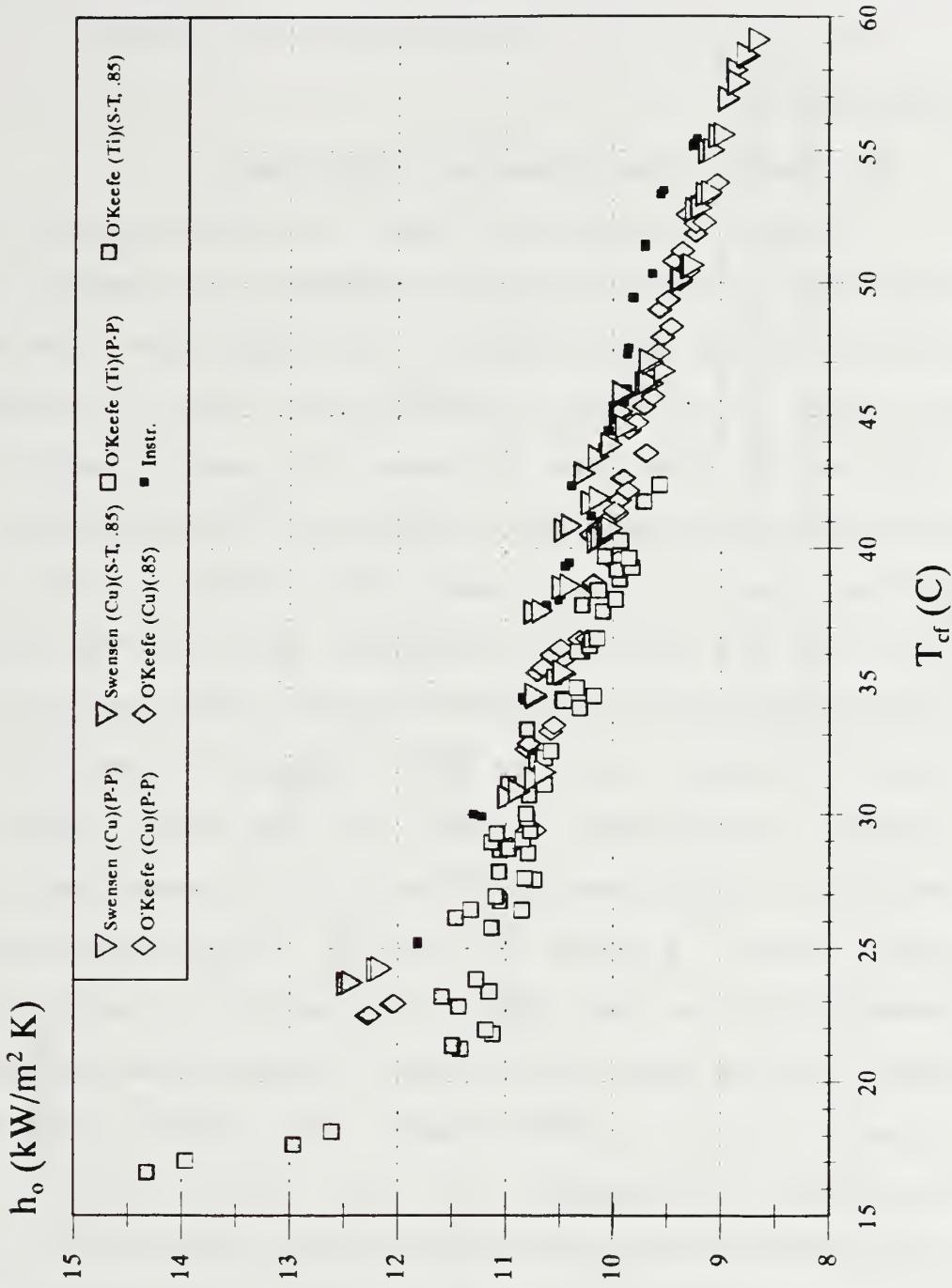
Figure 11. Comparison of the Outside Heat Transfer Coefficients for Atmospheric Pressure Using the Petukhov-Popov and Sieder-Tate ($Re^{.85}$) Correlations

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coefficient.

1. Overall Heat Transfer Coefficient

Figures 12 through 15 show the overall heat transfer coefficient values for each atmospheric and vacuum pressure run done on the smooth titanium and copper tube. The shape of the curve is related to the coolant flow rate through the tube; as the flow rate increases the overall heat transfer coefficient increases due to improved coolant mixing. It is obvious that in every case, the overall heat transfer coefficient is higher for the copper tube ($\approx$18% for the HEATEX insert data and $\approx$14% for the no insert data at a coolant flow rate of 2.5 m/s). Most of this increase in the overall heat transfer coefficient is due to the much smaller wall resistance (approximately a factor of 6) associated with the copper tube. Figures 12 through 15 also show excellent repeatability of the data. The effect of using a Heatex insert can be seen in Figure 16, which shows values of U_o averaged for all the data taken. The HEATEX insert gives a significant enhancement in the overall heat transfer coefficient of around 20% for a coolant flow rate of 2.25 m/s. The vapor shear forces also effect the overall heat transfer coefficient (U_o). It can be seen that U_o is higher for the vacuum runs ($U_\infty \approx$ 2 m/s) than the atmospheric runs ($U_\infty \approx$ 1 m/s) because of the higher vapor shear effect. However, this vapor shear effect is small ($\leq$5%) when compared to the effect that

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Figure 12. U_o vs. V_w for a Smooth Tube at Atmospheric Pressure with a HEATEX Insert

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Figure 13. U_o vs. V_w for a Smooth at Atmospheric Pressure with No Insert

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Figure 14. U_o vs. V_w for a Smooth Tube at Vacuum Pressure with a HEATEX Insert

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Figure 15. U_o vs. V_w for a Smooth Tube at Vacuum Pressure with No Insert

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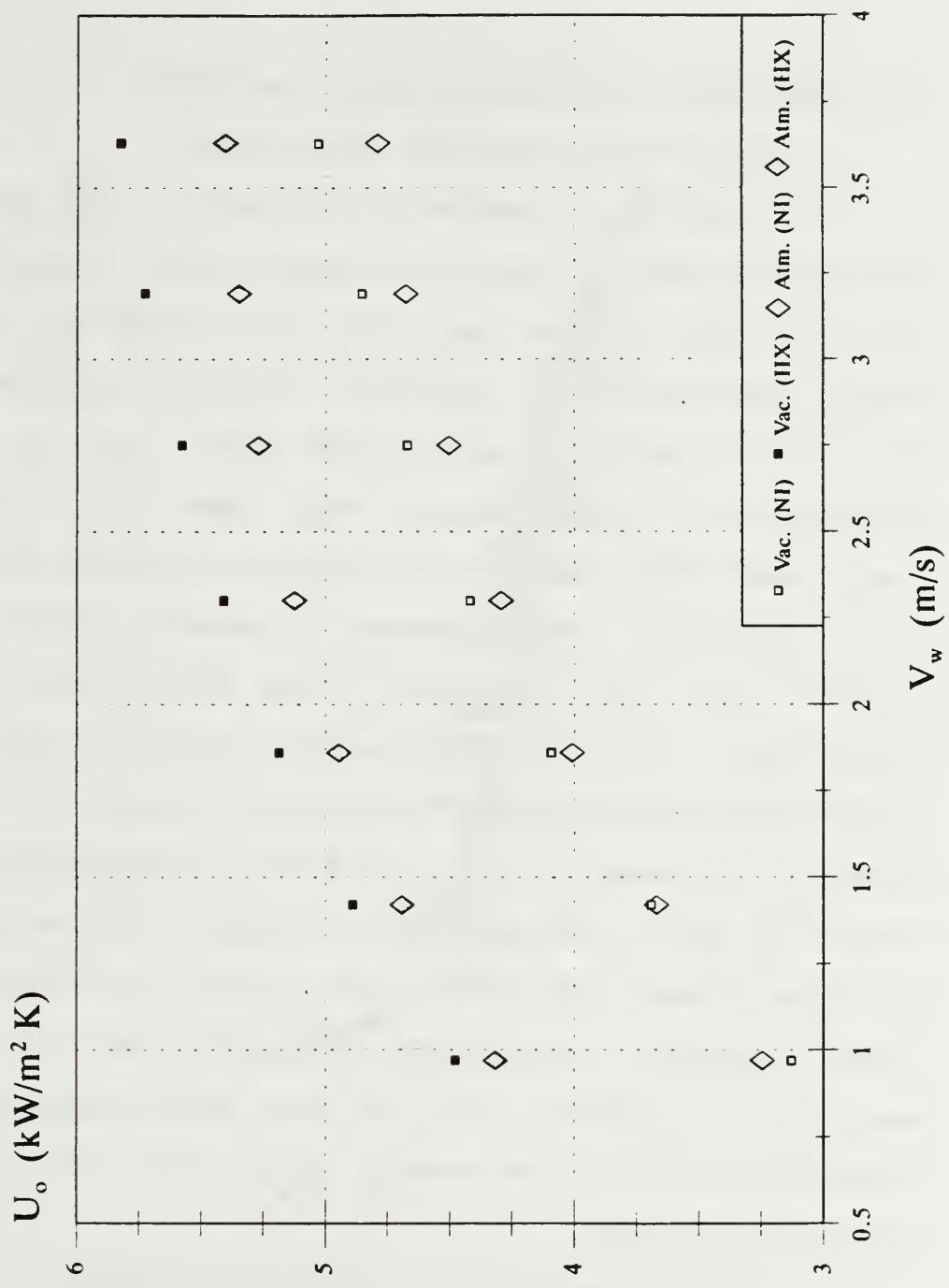
Figure 16. Effect of Vapor Velocity on Smooth Titanium Tubes Average U_o Values

the insert has at the same coolant velocity.

   2.   Outside Heat Transfer Coefficient

   The outside heat transfer coefficient is determined using the Nusselt [Ref. 10] equation based on ΔT_f, equation (4.12). Figures 17 and 18 show the outside heat transfer coefficient versus the temperature difference across the condensate film for all the smooth titanium tube data.   Several previous researcher's smooth copper tube data have also been reprocessed using the Petukhov-Popov correlation and plotted in the figures.   For atmospheric pressure, there is good agreement for all the copper tube data between all the researchers.   The titanium tube data, however, tends to fall below the copper tube data, agreeing more closely with Nusselt theory.   The reason for the two Nusselt theory lines in each figure is due to the different diameters for the copper and titanium tubes.   The vacuum data (Figure 17) shows the same lower values for the titanium tube.   The reason for the large scatter is probably due to the much smaller coolant temperature rise in the case of the titanium tube, making the data less accurate.

   In order to compare the outside heat transfer coefficient of the smooth tube to each of the enhanced tubes, the Nusselt coefficient, α, needs to be determined under similar conditions for each tube.   A summary of the results for the data reduction analysis for the leading coefficients (C_i)

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h₀ vs. T_cf
Atmospheric Pressure
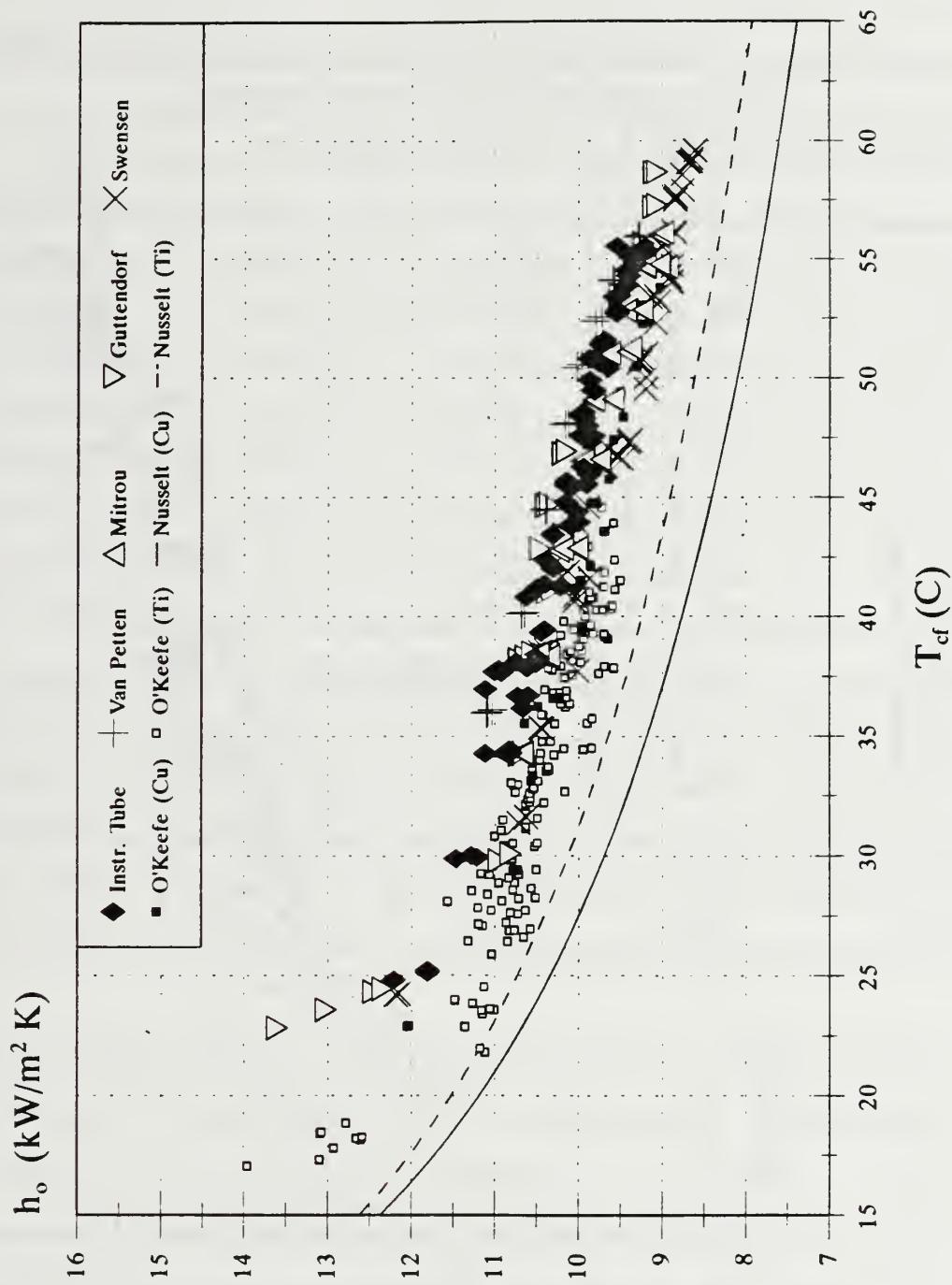
Figure 17. h₀ vs. ΔT_f for Smooth Tubes at Atmospheric Pressure

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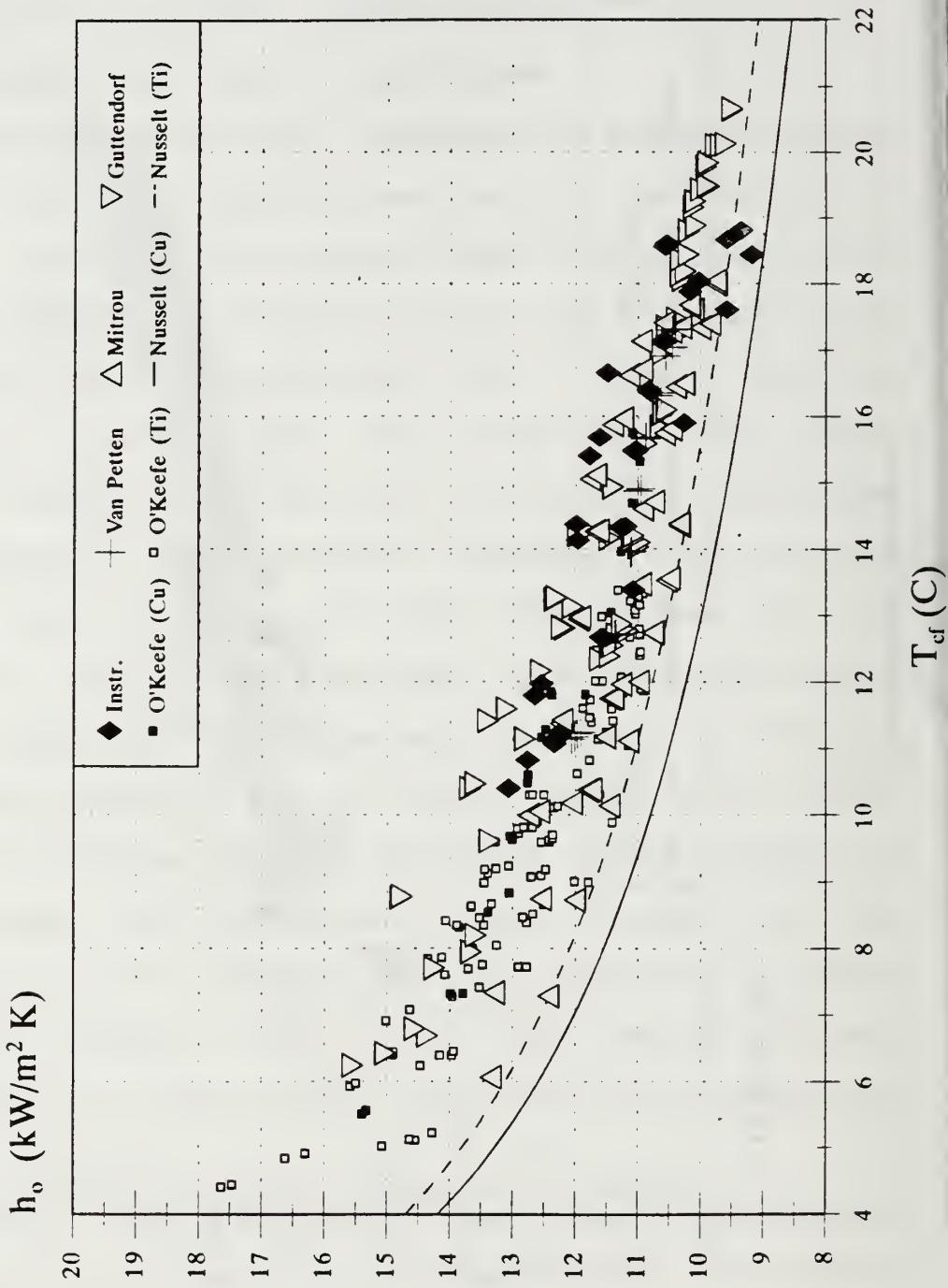
Figure 18. h_o vs. ΔT_f for a Smooth Tube at Vacuum Pressure

Table II. SMOOTH TITANIUM TUBE WITH A HEATEX INSERT (PRESENT WORK)

	Atmospheric Pressure HEATEX Insert			
	Petukhov-Popov		Sieder-Tate (Re^.85)	
Data Run	C_i	α	C_i	α
FONMAHT1	2.372	0.780	0.038	0.787
FONMAHT2	2.383	0.774	0.038	0.780
FONMAHT3	2.392	0.755	0.038	0.761
FONMAHT4	2.410	0.748	0.038	0.753
FONMAHT5	2.201	0.770	0.035	0.777
FONMAHT6	2.541	0.776	0.040	0.781
FONMAHT7	2.511	0.793	0.040	0.799
Atm. Avg.	2.401	0.776	0.038	0.777
Vacuum Pressure HEATEX Insert				
FONMVHT3	2.547	0.748	0.043	0.748
FONMVHT4	2.278	0.790	0.038	0.791
FONMVHT5	2.422	0.763	0.041	0.763
Vac. Avg.	2.416	0.767	0.041	0.767
Total Avgs.	2.406	0.770	0.039	0.774

using the Petukhov-Popov and Sieder-Tate (Re^.85) correlations, and the Nusselt coefficients (α) for the smooth titanium and copper tubes are presented in Tables II through VI. The printouts for all the data runs are given in Appendix D. The researcher initials are as follows: (G)=Guttendorf [Ref. 32], (M)=Mitrou [Ref. 9], (O)=O'Keefe, (S)=Swensen [Ref. 5], and (V)= Van Petten [Ref. 4].

When using the modified Wilson plot technique to reprocess the data, the leading coefficient for the inside heat transfer

Table III. SMOOTH TITANIUM TUBE WITH NO INSERT (PRESENT WORK)

	Atmospheric Pressure No Insert			
	Petukhov-Popov		Sieder-Tate (Re$^{.85}$)	
Data Run	C_i	α	C_i	α
FONMANT1	1.211	0.750	0.019	0.765
FONMANT2	1.185	0.760	0.018	0.776
FONMANT3	1.169	0.765	0.018	0.777
FONMANT4	1.181	0.765	0.018	0.778
FONMANT5	1.237	0.786	0.019	0.801
Avgs.	1.197	0.765	0.018	0.779
	Vacuum Pressure No Insert			
FONMVNT2	1.092	0.822	0.018	0.822
FONMVNT3	1.078	0.788	0.018	0.789
FONMVNT4	1.075	0.846	0.018	0.847
FONMVNT5	1.113	0.827	0.019	0.829
NI Avgs.	1.089	0.821	0.018	0.822
Total Avgs.	1.149	0.790	0.018	0.798

correlation can either be set with a user supplied value or left to "float", allowing the program to solve for the 'best' value of the coefficient itself as described in Chapter 4. Theoretically, if the leading coefficient is allowed to float, the coefficient should be about the same for all tubes with the same inner diameter. The tables show that the HEATEX inert enhances the inside heat transfer coefficient by a factor of around 2.5. Swensen [Ref. 5] and Micheal et al. [Ref. 33], show that as the vapor velocity across the tube

increases, the value of α increases because of the thinning of the film caused by the vapor shear. In Tables II through VI there is a general trend that the value of α increases between atmospheric ($U_\infty \approx 1.0$ m/s) and vacuum ($U_\infty \approx 2.0$ m/s) runs.

Table IV. SMOOTH COPPER TUBE WITH A HEATEX INSERT

Atmospheric Pressure HEATEX Insert				
	Petukhov-Popov		Sieder-Tate ($Re^{.85}$)	
Data Run/Researcher	C_i	α	C_i	α
FONMAHC1 (O)	2.809	0.832	0.044	0.835
FNMAVSH4 (S)	3.187	0.819	0.051	0.823
FNMAVSH8 (S)	3.083	0.824	0.049	0.830
FSOMASH3 (S)	3.031	0..818	0.048	0.826
Atm. Avgs.	3.028	0.823	0.048	0.828
Vacuum Pressure HEATEX Insert				
FONMVHC1 (O)	2.482	0.838	0.042	0.838
Total Avgs.	2.918	0.826	0.047	0.830

When the titanium tube is compared to the copper tube, the value of α for the titanium tube is significantly less tha n the α for the copper tube at the same vapor velocity. The value of α could be affected (between titanium and copper) by the difference in temperature profiles at the surface of the tube caused by the different material thermal conductivities. The copper tube will exhibit a much more uniform temperature profile around the tube than the titanium tube. This will affect the properties of the condensate film covering the

Table V. SMOOTH COPPER TUBE WITH A WIRE WRAP INSERT

Atmospheric Pressure Wire Wrap Insert				
	Petukhov-Popov		Sieder-Tate (Re	
Data Run/Researcher	C_i	α	C_i	α
SMTHSTA654 (V)	2.653	0.875	0.042	0.8
S001S1A3 (G)	2.722	0.855	0.043	0.8
S50A213 (M)	2.335	0.850	0.036	0.8
S50A220 (M)	2.272	0.834	0.035	0.8
Atm. Avgs.	2.495	0.853	0.039	0.8
Vacuum Pressure Wire Wrap Insert				
M1STV103 (V)	2.607	0.827	0.044	0.8
S001S1V3 (G)	2.538	0.818	0.043	0.8
S001S1V4 (G)	2.575	0.823	0.043	0.8
S001S1V5 (G)	2.644	0.815	0.044	0.8
S50V181 (M)	2.102	0.856	0.035	0.8
S50V184 (M)	2.142	0.802	0.036	0.8
Vac. Avgs.	2.435	0.823	0.041	0.8
Total Avgs.	2.459	0.835	0.040	0.8

tube, which in turn affect the values of α. Another reason could be the fact that it was much easier to get filmwise condensation on the titanium than on the copper tube, presumably because of the different surface wettablity characteristics of titanium and copper with water. This could lead to differences in the condensate film and even some dropwise condensation in the case of the copper tube.

Table VI. SMOOTH COPPER TUBE WITH NO INSERT

Atmospheric Pressure No Insert				
	Petukhov-Popov		Sieder-Tate $(Re^{.85})$	
Data Run/Researcher	C_i	α	C_i	α
FONMANC1 (O)	1.265	0.816	0.019	0.828
FSONMASN1 (S)	1.355	0.833	0.021	0.847
S001S0A2 (G)	1.347	0.858	0.021	0.875
Atm. Avgs.	**1.322**	**0.836**	**0.020**	**0.850**
Vacuum Pressure No Insert				
FONMVNC1 (O)	1.085	0.866	0.018	0.867
S001S0V2 (G)	1.056	0.904	0.017	0.909
S001S0V3 (G)	1.147	0.872	0.019	0.876
S50V177 (M)	0.970	0.774	0.016	0.858
Vac. Avgs.	**1.064**	**0.854**	**0.018**	**0.857**
Total Avgs.	**1.175**	**0.846**	**0.019**	**0.841**

C. ANALYSIS OF THE WIRE-WRAPPED SMOOTH TUBES

The seven wire-wrapped titanium smooth tubes fabricated for this thesis and two of the wire-wrapped copper tubes used by Mitrou [Ref. 9] were tested under vacuum and atmospheric conditions to find the enhancement compared to a smooth tube for a constant temperature drop across the condensate film. Previous research done in this area has tried to find the optimum relationship between this enhancement and the wire pitch, wire diameter, and the fraction of tube covered by wire.

The overall heat transfer coefficients are similar to the smooth tube curves except that any enhancement due to the wire

can be seen directly on this curve. The same effects caused by the insert and vapor shear (as mentioned previously) also apply to the wire-wrapped tubes. Figure 19 shows the overall heat transfer coefficient for tubes 4-7 at atmospheric pressure with a HEATEX insert. All other U_o data for the rest of the runs are listed in Appendix D.

Figure 20 shows how the outside heat transfer coefficients for tubes 6 and 7 compare with the smooth titanium tube at atmospheric pressure. Tubes 6 and 7 were the only wire-wrapped titanium tubes to show significant enhancement. Both of these tubes were wrapped with a 0.5 mm diameter wire with pitches of 4 mm (P/D_w = 7.92) and 2 mm (P/D_w = 4.02) respectively. Tube 6 showed enhancements between 23% and 30% for vacuum and atmospheric pressure respectively. Figures 21 and 22 show the outside heat transfer coefficient data for tubes 1 through 5. Tube 3 was the only tube to show a degradation in performance as compared to the smooth titanium tube. It had a 1.6 mm wire with a pitch of 3.40 mm (P/D_w = 2.13); the poor performance of this tube is attributed to the effects of condensate retention between the wires on the tube,which were clearly seen. The performance of tubes 1 and 2 were similar to the plain smooth tube. Tubes 4 and 5 showed an enhancement of about 10% over the smooth titanium tube. Tables VII through XI show the results from the data reduction scheme for C_i and α for each data run. The leading coefficients in front of the inside heat transfer correlation

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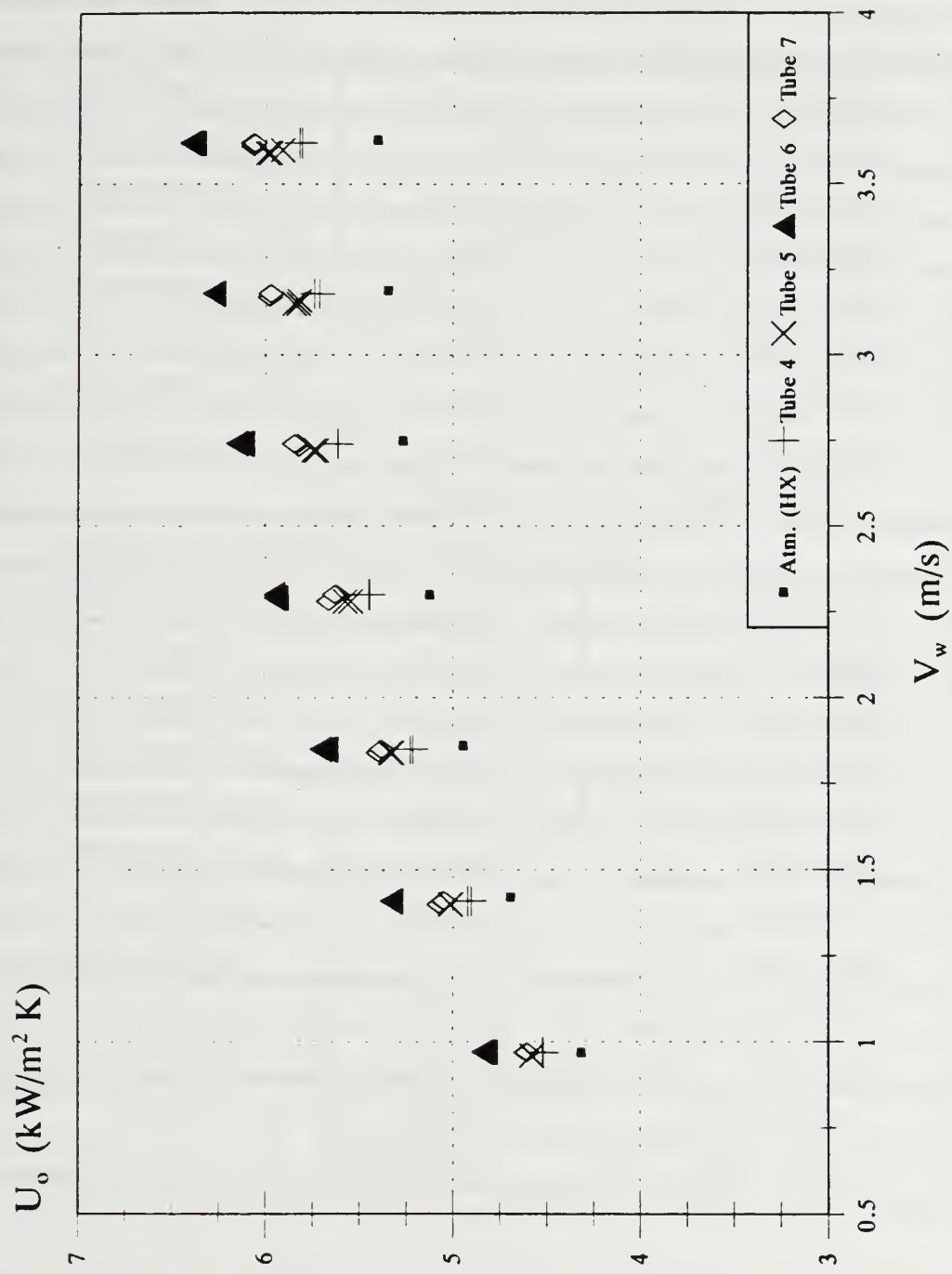
Figure 19. U_o vs V_w for Wire-Wrapped Tubes at Atmospheric Pressure with a Heatex Insert

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Table VII.   WIRE-WRAPPED SMOOTH TITANIUM TUBES WITH A HEATEX
INSERT

Atmospheric Pressure HEATEX Insert			
Data Run / Tube	C_i	α	E_T
FONMAH1T1 (1)	2.023	0.798	1.035
FONMAH2T3 (2)	2.448	0.806	1.046
FONMAH3T1 (3)	2.138	0.724	0.902
FONMAH4T1 (4)	2.379	0.853	1.106
FONMAH5T1 (5)	2.251	0.869	1.127
FONMAH6T2 (6)	2.389	0.993	1.289
FONMAH6T3 (6)	2.362	1.005	1.304
FONMAH7T1 (7)	2.237	0.925	1.200
Atm. Avg.	2.301		
Vacuum Pressure HEATEX Insert			
FONMVH1T1 (1)	1.892	0.802	1.045
FONMVH2T1 (2)	2.005	0.797	1.038
FONMVH2T2 (2)	1.948	0.787	1.026
FONMVH2T3 (2)	2.240	0.766	0.999
FONMVH3T2 (3)	1.866	0.618	0.714
FONMVH4T1 (4)	2.081	0.821	1.071
FONMVH5T1 (5)	2.014	0.842	1.097
FONMVH6T1 (6)	2.160	0.950	1.238
FONMVH6T2 (6)	2.214	0.946	1.233
FONMVH7T2 (7)	1.956	0.855	1.115
Vac. Avg.	1.967		
Total Avg.	2.115		

are consistent with the smooth tube data, as expected.

The copper tubes used by Mitrou [Ref. 9], tubes 68 and 71,
were tested to check the repeatability of Mitrou's data. As

Table VIII. WIRE-WRAPPED SMOOTH TITANIUM TUBES WITH NO INSERT

Atmospheric Pressure No Insert			
Data Run / Tube	C_i	α	E_r
FONMAN1T1 (1)	1.131	0.783	1.022
FONMAN2T1 (2)	1.095	0.801	1.047
FONMAN3T1 (3)	1.034	0.698	0.888
FONMAN4T1 (4)	1.377	0.791	1.034
FONMAN5T1 (5)	1.099	0.837	1.093
FONMAN6T1 (6)	1.120	1.019	1.331
FONMAN7T1 (7)	1.191	0.866	1.131
Atm. Avg.	1.150		
Vacuum Pressure No Insert			
FONMVN1T1 (1)	1.024	0.838	1.021
FONMVN2T1 (2)	0.998	0.818	0.997
FONMVN3T1 (3)	0.911	0.636	0.702
FONMAN4T1 (4)	1.139	0.825	1.005
FONMAN5T1 (5)	0.978	0.843	1.027
FONMAN6T1 (6)	1.043	1.013	1.235
FONMVN7T1 (7)	0.978	0.870	1.060
Vac. Avg.	1.010		
Total Avg.	1.080		

discussed earlier, it was difficult to get good filmwise condensation over the entire tube. The enhancements found were higher than those given by Mitrou's data (reprocessed using the Petukhov-Popov correlation) for tubes 68 and 71; for tube 68, differences of 10% and 17% and for tube 71, differences of 45% and 6% for atmospheric and vacuum pressures

Table IX. WIRE-WRAPPED SMOOTH COPPER TUBES WITH A HEATEX INSERT

Atmospheric Pressure HEATEX Insert			
Data Run	C_i	α	E_T
FONMAH68C1	2.807	1.316	1.719
FONMAH71C1	3.069	1.722	2.192
Atm. Avg.	2.938		
Vacuum Pressure HEATEX Insert			
FONMVH68C1	2.549	1.289	1.570
FONMVH71C2	2.765	1.414	1.560
Vac. Avg.	2.657		
Total Avg.	2.797		

respectively. This increase in enhancement could have been due to small patches of dropwise condensation on the surface of the tubes, although it was difficult to see during the experiments due to condensate on the window. Figure 23 shows the comparison of tubes 6 and 71 to a smooth titanium tube. Tubes 6 and 71 have similar pitches and the same wire diameter and should, in theory, give similar values for the outside heat transfer coefficient. However, the enhancement given by the wire-wrapped copper tube (tube 71) is significantly higher ($\approx$35%) than the enhancement given by the wire-wrapped titanium tube (tube 6). This trend tends to reiterate the idea that tube surface wettablity characteristics or tube thermal conductivity may affect the outside heat transfer coefficient.

Table X.   WIRE-WRAPPED SMOOTH COPPER TUBES WITH A WIRE WRAP INSERT

Atmospheric Pressure Wire Wrap Insert			
Data Run/Researcher	C_i	α	E_T
S68A311 (M)	2.686	1.360	1.616
S71A305 (M)	2.685	1.489	1.769
S71A314 (M)	2.692	1.473	1.749
Atm. Avg.	2.688		
Vacuum Pressure Wire Wrap Insert			
S68V283 (M)	2.452	1.182	1.401
S68V293 (M)	2.485	1.166	1.382
S71V296 (M)	2.503	1.267	1.501
Vac. Avg.	2.480		
Total Avg.	2.584		

In order to see the relationship between the wire pitch, wire diameter and the enhancement, the values of enhancement versus the wire pitch to wire diameter ratio are plotted in Figure 24. Also shown are the newly reprocessed data (using the Petukhov-Popov correlation) from Mitrou [Ref. 9], and the data presented by Sethumadhavan and Rao [Ref. 15]. Even though the experiments were conducted very carefully, the titanium tube data tends to show the most scatter. The data of Sethumadhavan and Rao [Ref. 15] and Mitrou [Ref. 9] demonstrate a maximum enhancement at a P/D_w of about 5. The present data do not show such a clear maximum and tube 6 (P/D_w = 7.96) does not appear to be in line with the data of Sethumadhavan and Rao or Mitrou. Extra experiments were done
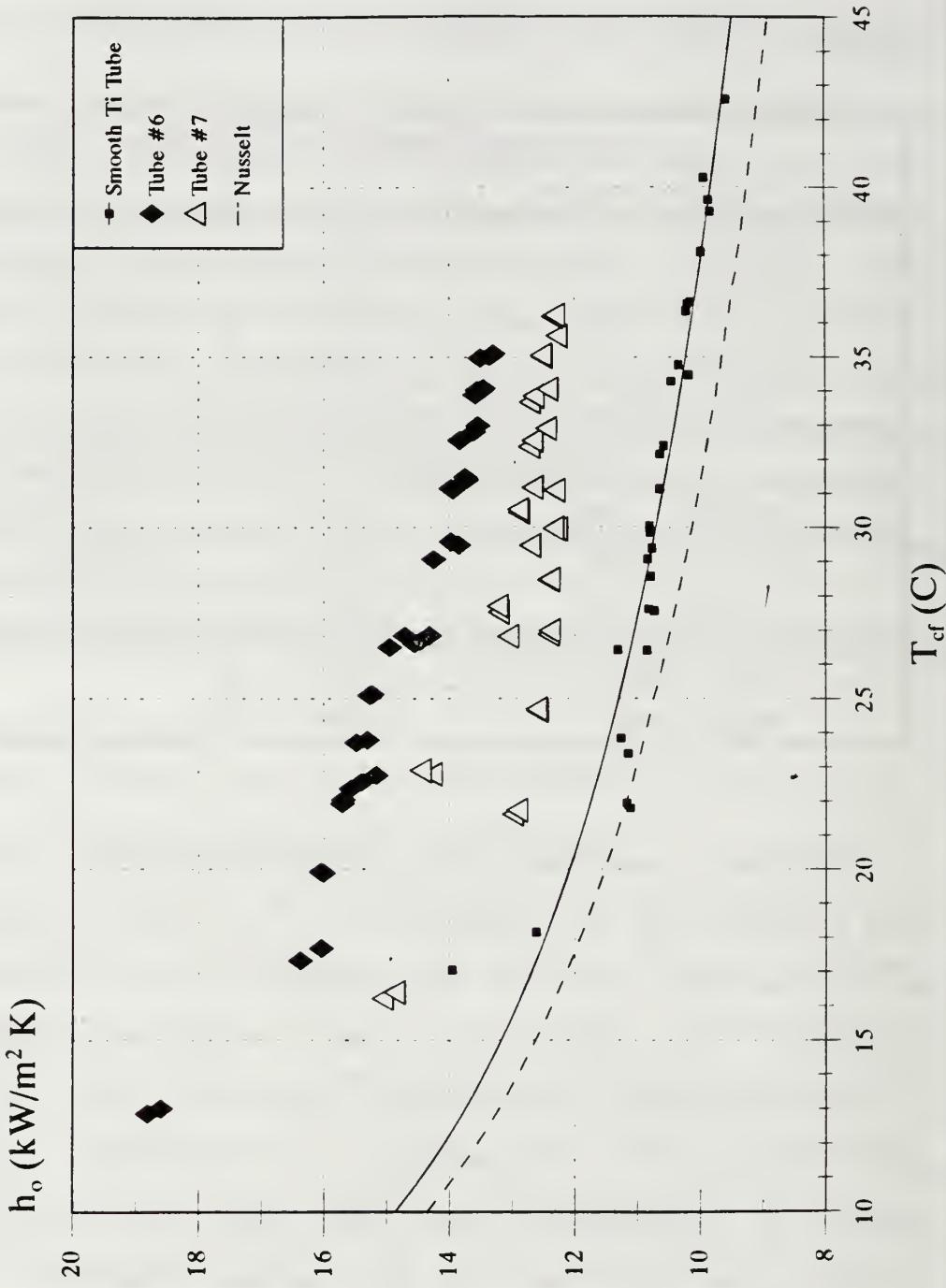
Figure 20.   Comparison   of   the   Outside   Heat   Transfer.
Coefficients of Tubes 6 and 7 with a Smooth Titanium Tube
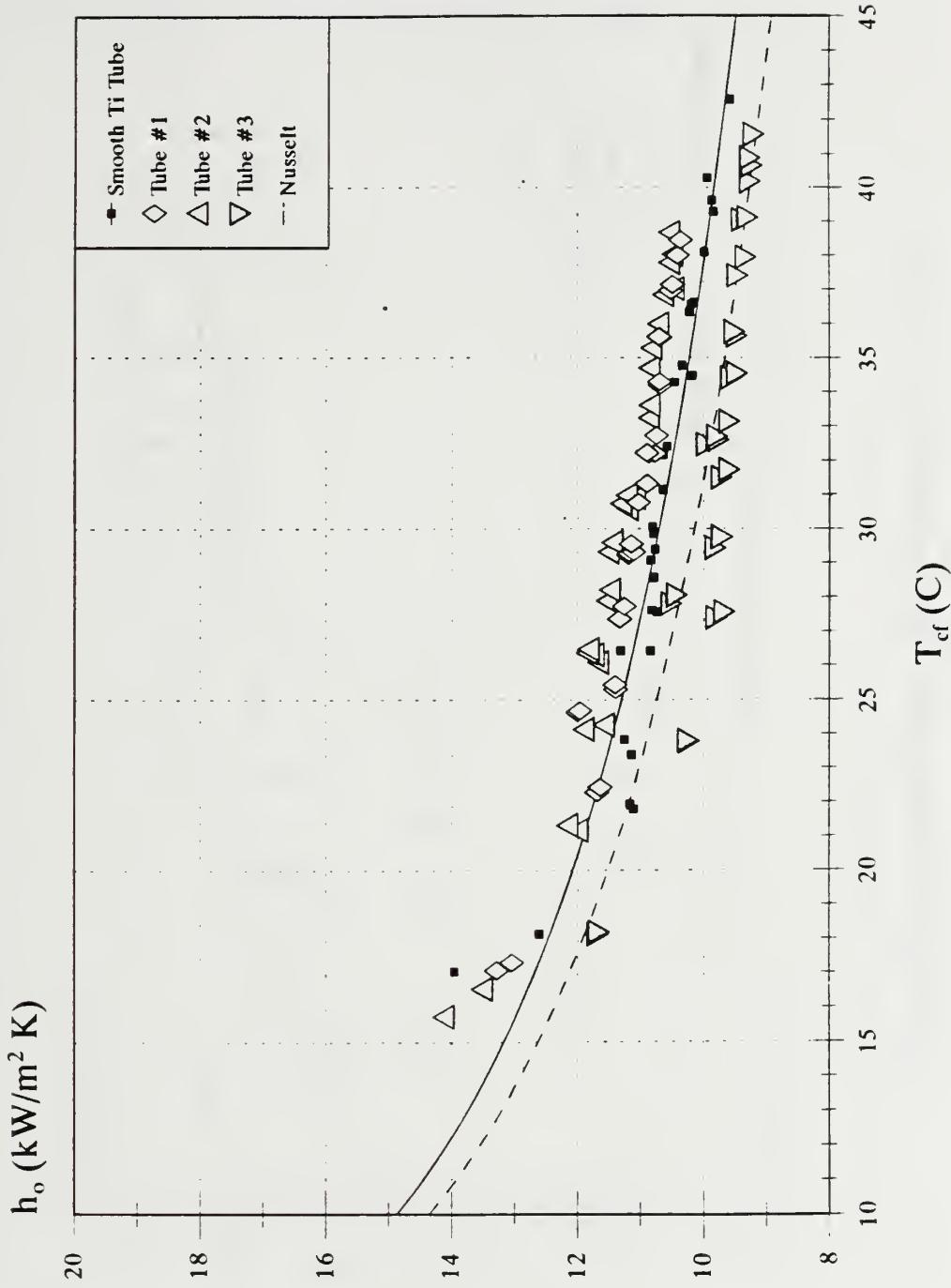
Figure 21.   Comparison   of   the   Outside   Heat   Transfer
Coefficients of Tubes 1,2, and 3 to a Smooth Titanium Tube

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Figure 22. Comparison of the Outside Heat Transfer Coefficients for tubes 4 and 5 to a Smooth Titanium Tube
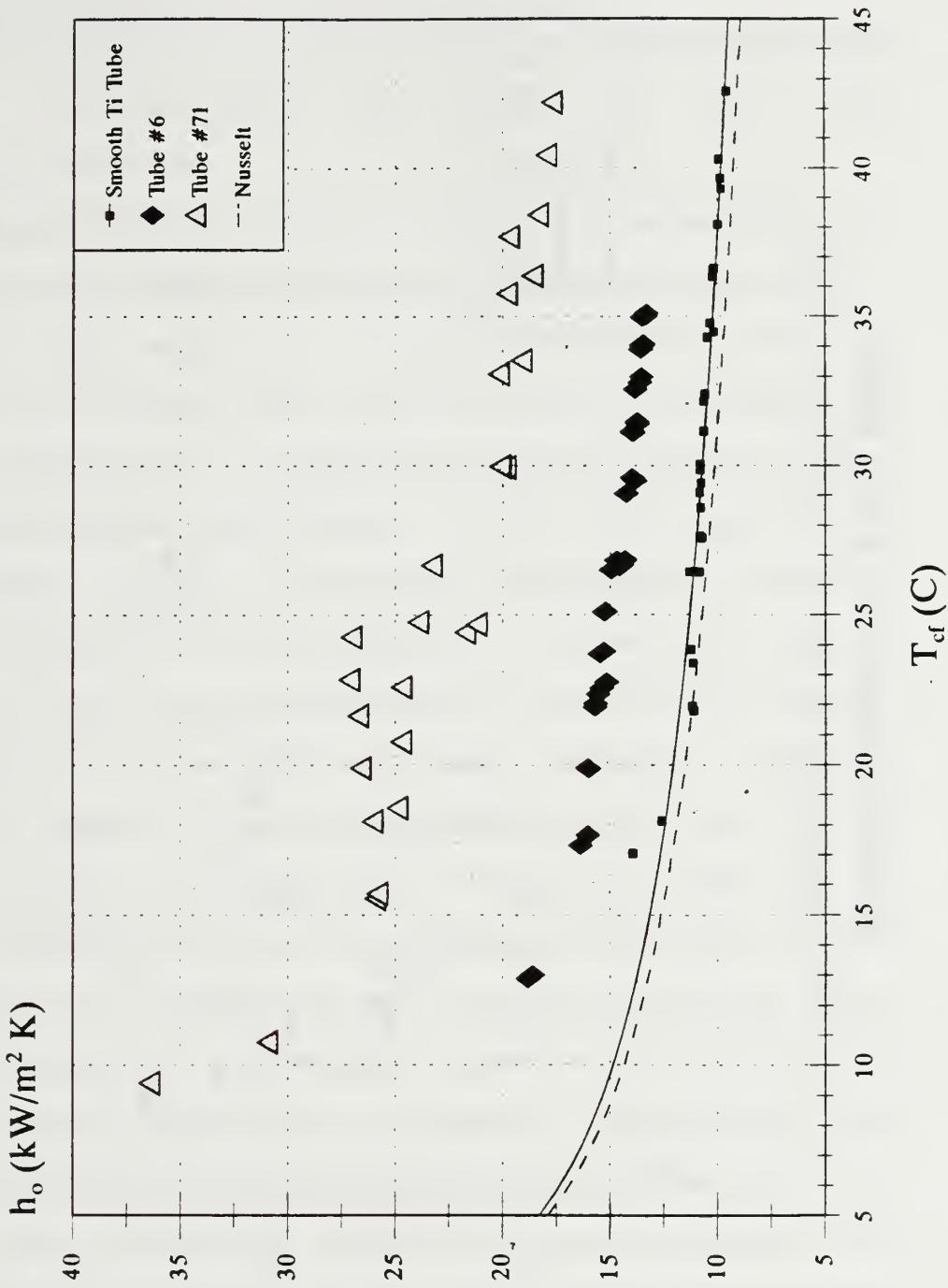
Figure 23.   Comparison of the Outside Heat Transfer
Coefficients between the Titanium and Copper Tubes

Figure 24. Comparison of the Enhancement vs. P/D$_w$ Ratio of the Data from Mitrou, O'Keefe, and Sethumadhavan & Rao

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on tube 6 to check the repeatability with essentially the same results. It would appear that P/D_w is not such a good correlating parameter.

Instead of looking at the P/D_w ratio, the enhancement can also be compared to the percentage of the tube surface that is covered by the wire, F. In the research done by Sethumadhavan and Rao [Ref. 15], the optimal coverage of a tube was found to be 21%. The fractional wire coverage values were determined for the present titanium and copper wire-wrapped tubes. Figure 25 shows the enhancement versus the fraction of the tube covered by wire. The value of 21% for the optimal value of F does not seem to hold for the data in this thesis or for the data of Mitrou. However, this does seem to be a better correlating parameter than P/D_w, and the maximum value of the fractional tube coverage seems to lie somewhere between 10% and 30%. The optimal value of F for the copper tube used by Mitrou and the titanium tube appear to be different and there is a definite increase in F as the tube material thermal conductivity increases. Unfortunately, the material of the tube used by Sethumadhavan and Rao [Ref. 15] is not given, although the data would suggest some intermediate conductivity material such as aluminum. Indeed, in another paper by Mehta and Rao [Ref. 22] aluminum tubes were used.
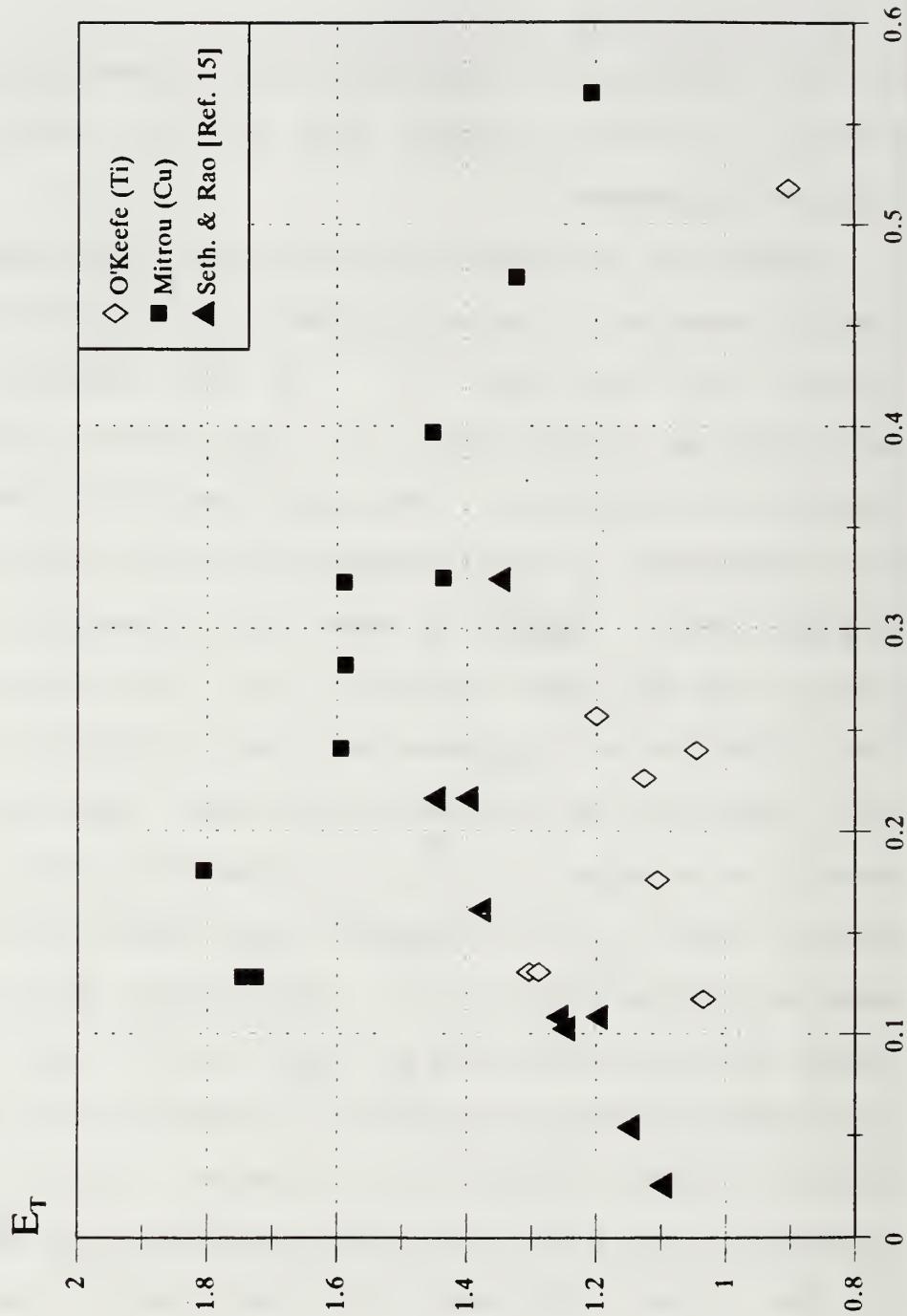
Figure 25. Comparison of the Enhancement vs. F for the data
of Mitrou, O'Keefe, and Sethumadhavan & Rao

D. ANALYSIS OF THE ROPED AND WIRE-WRAPPED ROPED TITANIUM TUBES

Four different roped tubes were tested. One tube was a plain LPD KORODENSE titanium tube that was used to get baseline data for comparing to the plain smooth titanium tube and to the wire-wrapped LPD KORODENSE titanium tubes. The values of the overall heat transfer coefficient are much higher (≈20%) for the LPD KORODENSE tubes when compared to the plain smooth titanium tube. The reason for the increase in the overall heat transfer coefficient is mainly because of the corrugation of the LPD tube on the inside which increases the turbulence of the coolant flow, thereby reducing the inside thermal resistance.

Tables 12 and 13 give the results of the data reduction procedure of all the roped tubes in comparison with the smooth titanium tube. The plain LPD tube consistently gave enhancements of about 20% in the outside heat transfer coefficient, as seen in Figure 26. The wire-wrap was put on the roped tube to try and get an additional enhancement on the outside of the tube. By looking at Tables 12 and 13, the only wire-wrapped LPD tube that showed any enhancement over the plain LPD tube was tube L3 (D_w= 0.5 mm). Figure 27 shows the outside heat transfer coefficients for the three wire-wrapped LPD tubes. The wire-wrapped LPD tubes were also checked to see if there was any relation between P/D_w or F and the enhancement over a plain LPD tube (h_e/h_{LPD}). Figures 28 and 29

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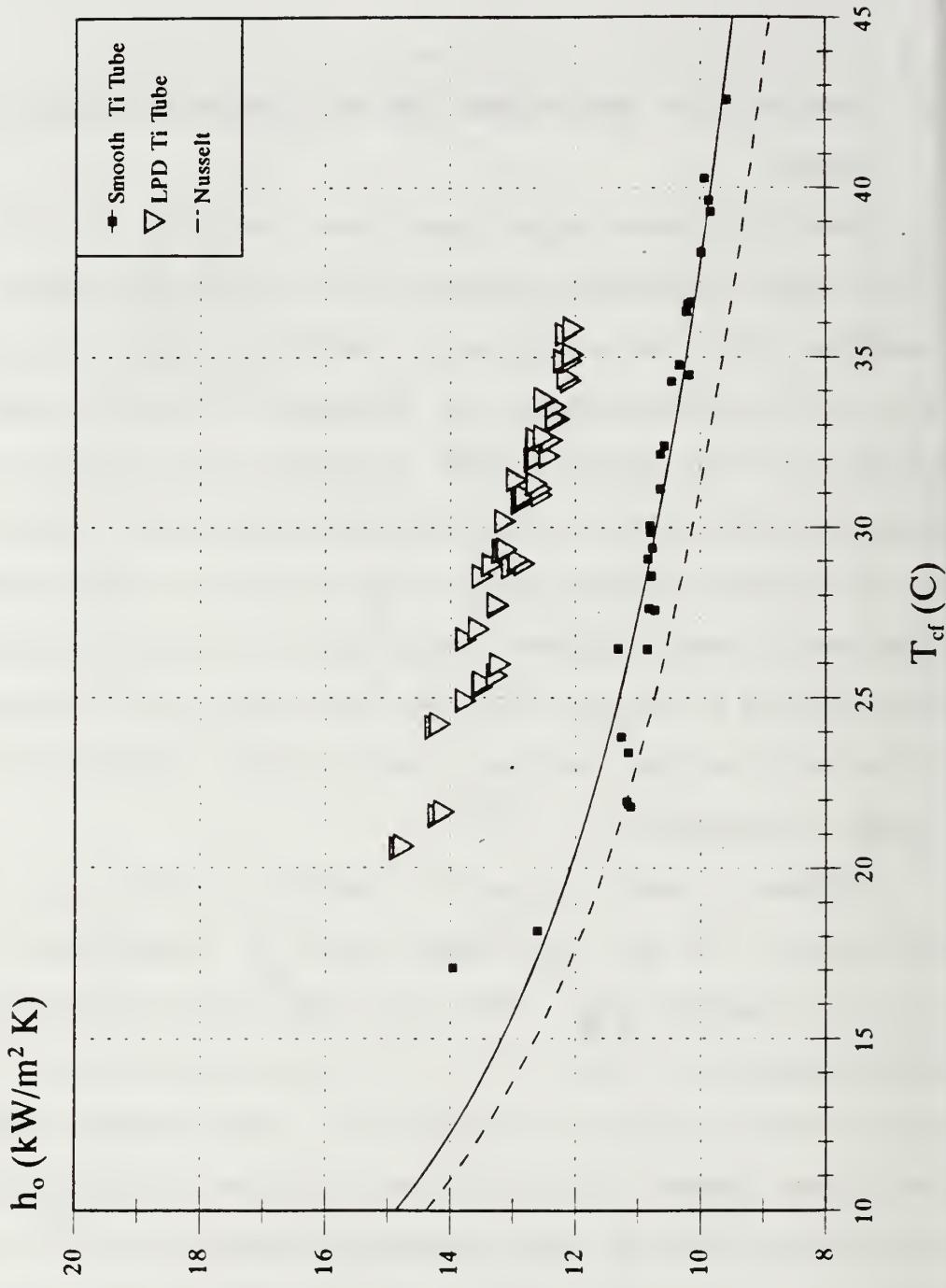
Figure 26.   Comparison   of   the   Outside   Heat   Transfer
Coefficients for the plain LPD KORODENSE Tube and the Smooth
Titanium Tube

Table XI. LPD KORODENSE TUBES WITH A HEATEX INSERT

Atmospheric Pressure HEATEX Insert			
Data Run / Tube	C_i	α	E_T
FONMAHLT2 (L)	2.903	0.903	1.171
FONMAHLT3 (L)	2.892	0.916	1.188
FONMAHL1T1 (L1)	2.667	0.890	1.154
FONMAHL2T1 (L2)	2.639	0.909	1.179
FONMAHL3T1 (L3)	2.835	0.968	1.256
Atm. Avg.	2.787		
Vacuum Pressure HEATEX Insert			
FONMVHLT1 (L)	2.717	0.945	1.232
FONMVHLT2 (L)	2.669	0.950	1.238
FONMVHL1T2 (L1)	2.317	0.880	1.147
FONMVHL2T3 (L2)	2.426	0.890	1.161
FONMVHL3T2 (L3)	2.609	0.995	1.297
Vac. Avg.	2.548		
Total Avg.	2.667		

show respectively the relationship between P/D_w and F to the enhancement over the plain LPD tube. Since the pitch here is fixed, Figure 28 indicates that there may be further enhancement possible if a smaller diameter wire is used. Figure 29 suggests there may be an optimal fractional coverage of the tube between 0 and 0.07. Based on the results from the wire-wrapped smooth titanium tubes, the maximum enhancement seen was about 30%; for the plain LPD tube over the plain smooth titanium tube the enhancement was about 20%.

Table XII. LPD KORODENSE TUBES WITH NO INSERT

Atmospheric Pressure No Insert			
Data Run / Tube	C_i	α	E_T
FONMANLT2 (L)	2.056	0.919	1.201
FONMANLT3 (L)	1.993	0.941	1.230
FONMANL1T1 (L1)	2.036	0.869	1.135
FONMANL2T1 (L2)	2.057	0.890	1.163
FONMANL3T1 (L3)	2.202	0.933	1.219
Atm. Avg.	2.069		
Vacuum Pressure No Insert			
FONMVNLT2 (L)	1.869	0.953	1.161
FONMVNLT3 (L)	1.862	0.956	1.165
FONMVNL1T2 (L1)	1.784	0.855	1.041
FONMVNL2T3 (L2)	1.839	0.869	1.059
FONMVNL3T2 (L3)	2.041	0.942	1.148
Vac. Avg.	1.879		
Total Avg.	1.974		

Therefore, the maximum additional enhancement expected from
wire-wrapping the LPD tube with a smaller diameter wire would
be about 10%.

One reason the larger diameter wires did not improve the
outside enhancement of the LPD tubes is that there was more
condensate retained between the wires than with the plain LPD
tube. This additional condensate causes a thicker condensate
film across the lower portion of the tube, resulting in less
overall heat transfer. The smallest wire (0.5 mm) fitted into
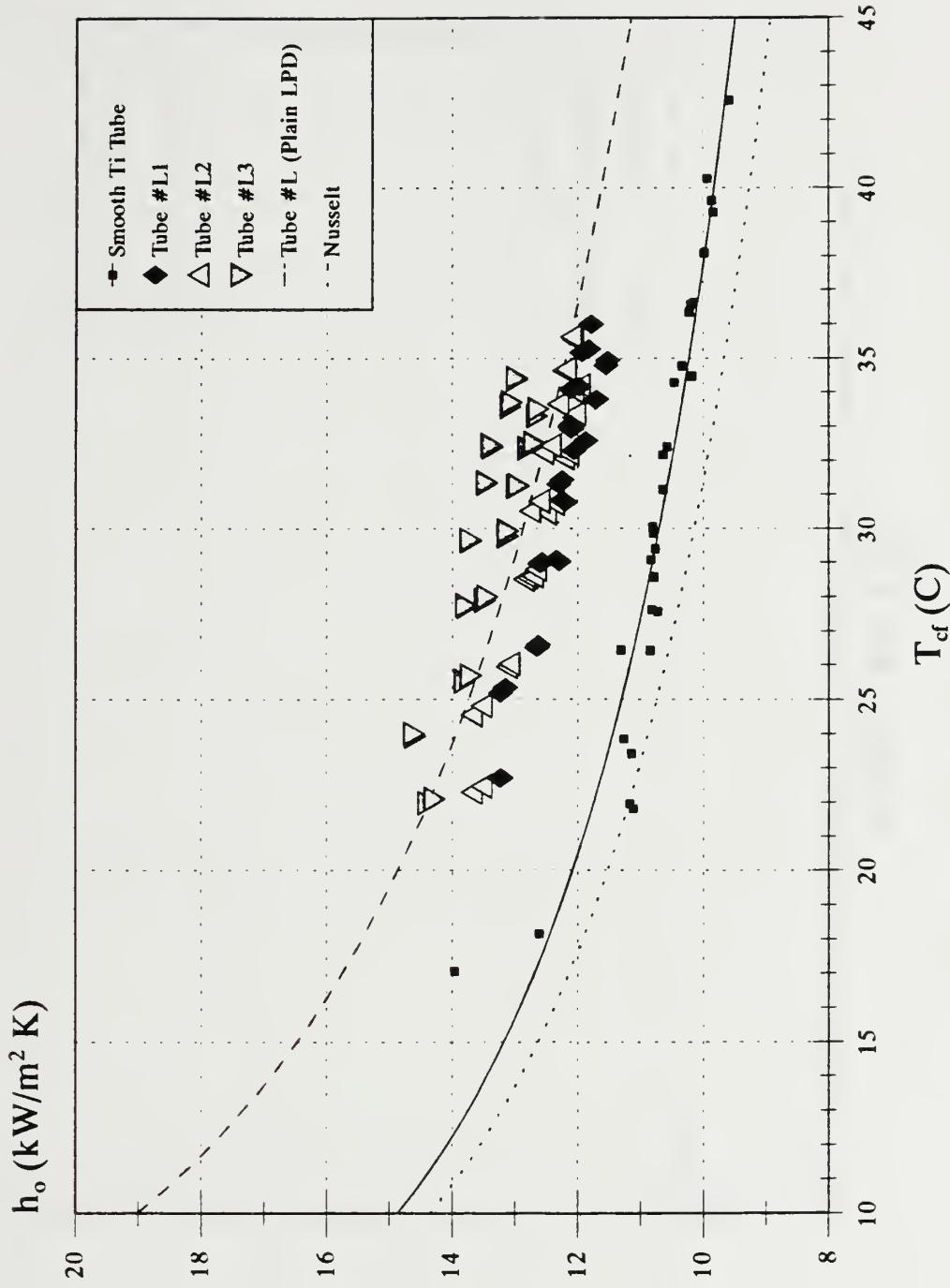
Figure 27. Comparison of the Outside Heat Transfer Coefficient for the Wire-Wrapped LPD KORODENSE Titanium Tubes and the Smooth Titanium Tube

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Figure 28.   Comparison of h_e/h_{os} vs. P/D_w Ratio for the Wire-
Wrapped LPD KORODENSE Tubes

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h_e/h_{LPD} vs. F

Wire-Wrapped LPD KORODENSE Titanium Tubes
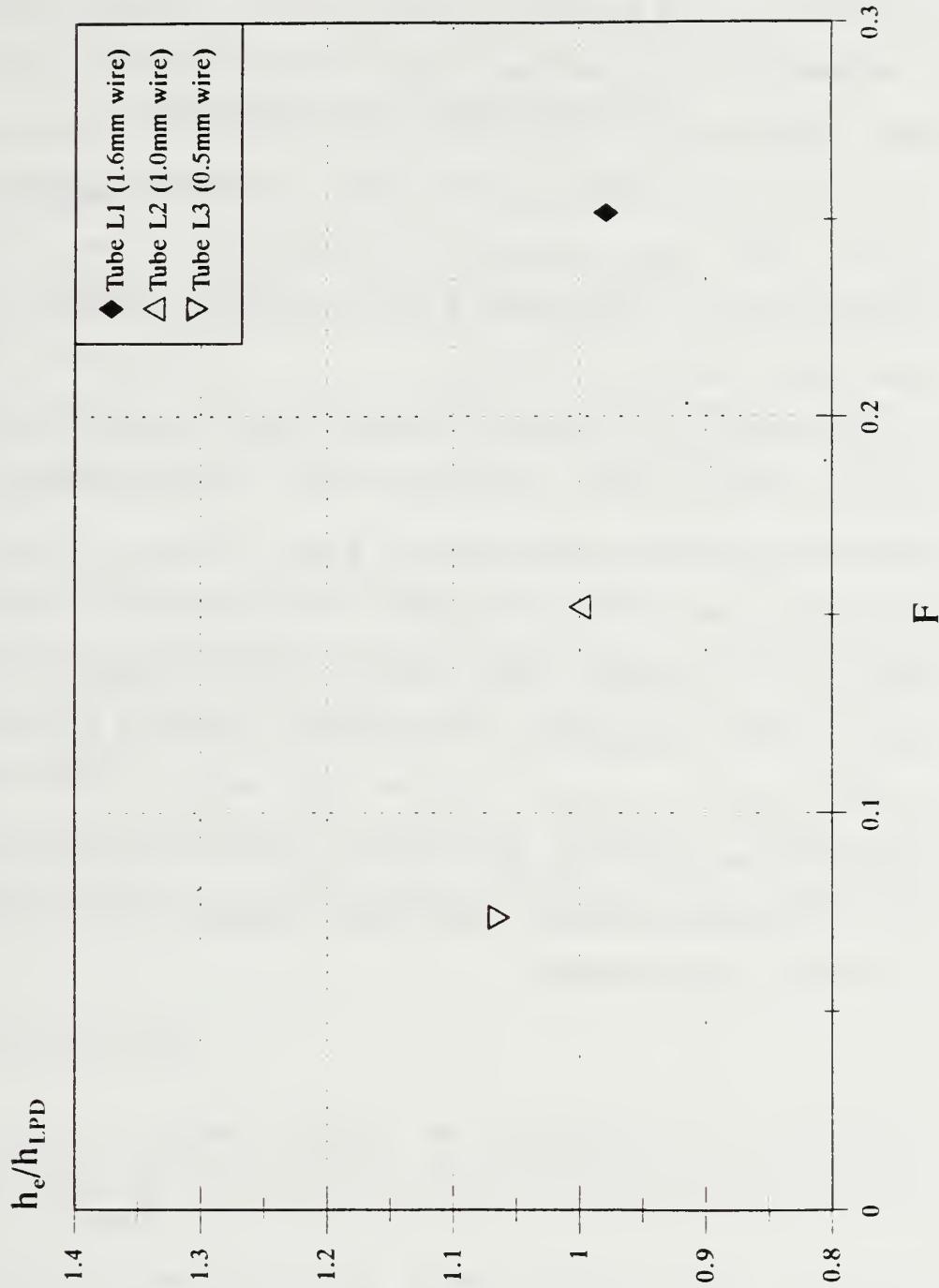
Figure 29. Comparison of h_e/h_{LPD} vs. F for the Wire-Wrapped LPD KORODENSE tubes

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the groove of the roped tube more closely, so that the amount of condensate retained was about the same as for a plain LPD tube. Since there was no additional condensate retention, the wire was better able to draw the condensate film to the groove. The larger pressure differential leads to greater thinning of the condensate film and thus a reduction in the vapor side thermal resistance.

In summary, the maximum enhancement in the outside heat transfer coefficient realized for a wire-wrapped smooth titanium tube was $\approx 30\%$ with a $P/D_w = 7.96$. A plain LPD KORODENSE tube showed consistent enhancements of $\approx 20\%$ in the outside heat transfer coefficient when compared to a smooth tube. There only seems to be a minimal gain in wire-wrapping an LPD tube to further improve the outside heat transfer coefficient. However, one benefit to wire-wrapping an LPD tube would be to reduce the effects of condensate inundation in a bundle arrangement.

CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. The Petukhov-Popov inside heat transfer coefficient correlation can be used to give accurate results in this test apparatus.

2. Enhancements in the outside heat transfer coefficient of up to 30% were obtained using a wire-wrapped titanium tube, when compared to the smooth titanium tube. (P/D_w = 7.92)

3. An optimal value of the fractional wire coverage of the tube of between 10% and 30% was found.

4. For an LPD KORODENSE titanium roped tube, an enhancement in the outside heat transfer coefficient of up to 20% over the smooth titanium tube was obtained. Using a wire-wrap on the LPD KORODENSE tube showed little further enhancement.

5. The surface wettability characteristics and perhaps the thermal conductivity of the tube material seems to have an influence on the outside heat transfer coefficient and possibly the optimal fractional wire coverage.

B. RECOMMENDATIONS

1. A set of tubes should be fabricated of different materials with fractional wire coverage of the tube in the range of 0.1 to 0.3, using different wire diameters and pitches.

2. Determine the effect of vapor velocity and inundation effects on the titanium wire-wrapped tubes. Use the Fujii [Ref. 12] correlation for the outside heat transfer coefficient when reprocessing the data.

3. Fabricate several more wire-wrapped LPD KORODENSE tubes using thinner wire diameters (0.1 mm, 0.2 mm, and 0.3 mm). To determine if there is a significant increase in

the enhancement of the outside heat transfer coefficient and an optimal value for the fractional wire coverage of the tube.

4. Reprocess the data sets using all the data for a given configuration (i.e. pressure, insert used, etc...) to determine more accurate values of C_i and α.

5. Conduct bundle tests to see if condensate inundation is reduced with wire-wrapped smooth and roped tubes.

APPENDIX A. SYSTEM CORRECTIONS

A. FRICTIONAL TEMPERATURE CORRECTIONS

When the coolant flows through the tube there is a temperature rise in the bulk fluid due to frictional heating. The amount of heating is dependent on the fluid velocity and the inside geometry of the tube. The actual temperature is small, but it can have a significant effect on the calculation for the overall heat transfer coefficient. The titanium tubes had a smaller temperature rise across the tube than the copper tubes, so the effect of the frictional heating is much greater. Measurements were made for the smooth titanium tube on August 7, 1992 and August 14, 1992 for the LPD KORODENSE titanium tube. The data is plotted in Figures A.1 and A.2. Runs were conducted with and without the HEATEX insert. The data was curve fitted to a third order polynomial as shown in Table A.1.

Table A.1   FRICTION TEMPERATURE RISE EQUATIONS

Tube/Insert Type	Polynomial Equation
Smooth/None	$T_{rise} = -8.843 \times 10^{-5}V^3 +1.799 \times 10^{-3}V^2 -7.526 \times 10^{-4}V -4.617 \times 10^{-5}$
Smooth/HEATEX	$T_{rise} = -3.305 \times 10^{-5}V^3 +2.122 \times 10^{-3}V^2 +9.737 \times 10^{-4}V +2.091 \times 10^{-4}$
LPD/None	$T_{rise} = 4.133 \times 10^{-5}V^3 +6.013 \times 10^{-4}V^2 +1.880 \times 10^{-3}V -3.386 \times 10^{-4}$
LPD/HEATEX	$T_{rise} = -2.781 \times 10^{-5}V^3 +1.893 \times 10^{-3}V^2 +9.202 \times 10^{-4}V +2.089 \times 10^{-4}$

where: T_{rise} = temperature rise (°K)
            V = fluid velocity (m/s)
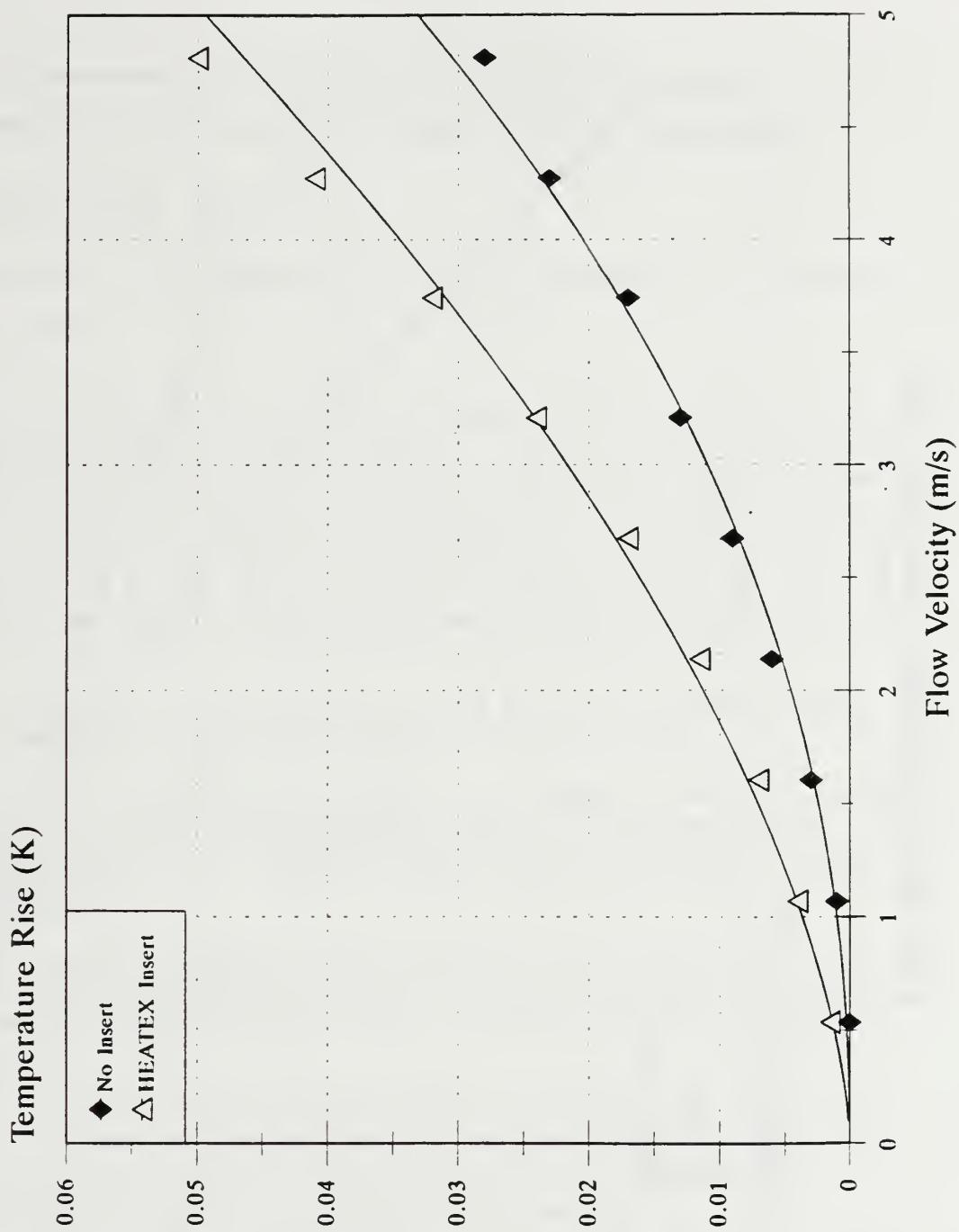
Figure A.1 Frictional Temperature Rise Curves for the Smooth
Titanium Tube with a HEATEX Insert and No Insert.

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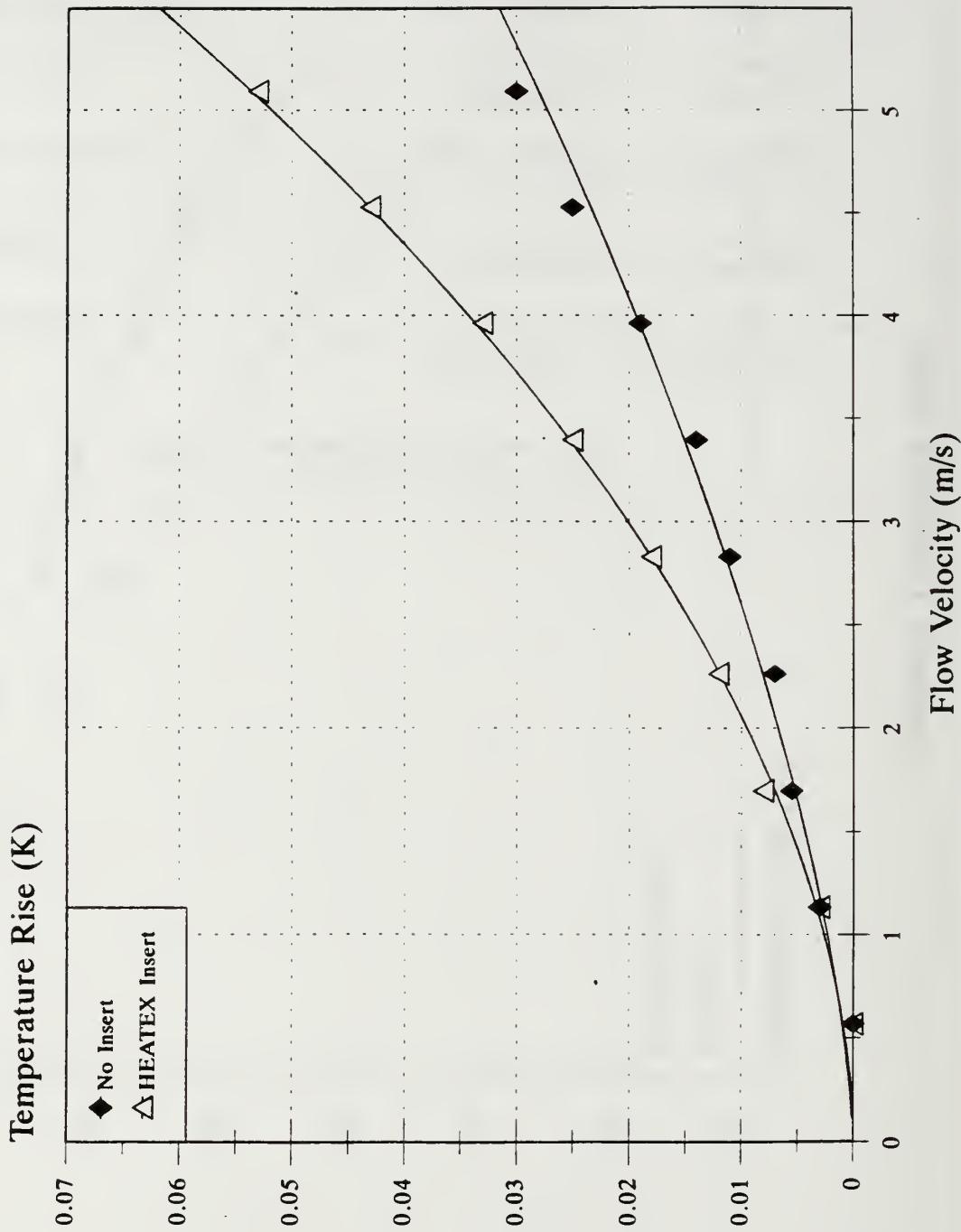
Figure A.2   Frictional Temperature Rise Curves for the LPD
KORODENSE Titanium Tube with a HEATEX Insert and No Insert

APPENDIX B. SYSTEM STARTUP AND SHUTDOWN PROCEDURES

A. SYSTEM STARTUP PROCEDURE

When preparing the system for taking data the following should be done:

1. Ensure the boiler section of the system is filled with distilled water, approximately 4 to 6 inches above the heaters. To fill the boiler a hose is attached between the distilled water tank and the boiler fill/drain valve. Ensure the vent valve by the auxiliary condenser is open prior to gravity filling the boiler. The boiler can be drained by ensuring the hose is removed from the boiler fill/drain valve. Then open the fill/drain valve and let the water drain to the bilge area below the boiler.

2. If the boiler has the appropriate water level then ensure the vent valve and fill/drain valve are shut.

3. Energize the data acquisition system, computer, and printer. Load the software program DRPOK and check for proper operation. Before starting any heaters check all thermocouples to ensure they are reading ambient temperature.

4. Open the fill valve to the coolant sump tank and set the flow rate such that the drain box does not overflow. (the valve is located to the left of the boiler heater control panel.)

5. Turn on the cooling water supply pumps and set the flow rate between 40% to 60% and check for leaks in the test section. Secure the flow and coolant supply pumps.

6. Open the valve supplying water to the auxiliary condenser unit and adjust the flow rate to at least 30% and check for leaks in the system. When the leak check is complete reset the flow rate as desired but at least greater than 10%.

7. CAUTION: prior to energizing any heaters ensure that the system is under a vacuum. To draw a vacuum on the system, ensure the drain valve on the plexiglas container

is shut. Check that there is flow to the sump tank, then energize the vacuum pump and open the suction valve located on the side of the auxiliary condenser. Allow the vacuum pump to run until the system pressure is below 3 psia, then shut the suction valve and secure the vacuum pump.

8. The heaters may be energized if the system is confirmed to be under vacuum conditions. To energize the heaters three switches must be placed in the "ON" position. The first switch is located on power panel p5, switch #3, in the main hallway adjacent to H-106. The second switch, the heater load bank circuit breaker, is located on the left side of the boiler heater control panel. The final switch, the condensing rig boiler power switch, is located on the front of the boiler heater control panel. When the heaters are energized, the power level should be set at 50 volts (40 volts if the system is below 2 psia to limit the vibrational shock to the system from vapor bubble formation). As the system warms up, the power can be increased at 10 volt increments until the desired setting is reached.

9. As the system warms up and the system pressure rises above 4 psia, then the non-condensible gases need to be flushed out of the system by drawing a vacuum on the system following step 7. To ensure the non-condensible gases collect at the base of the auxiliary condenser, coolant flow should remain secured and the flow rate to the auxiliary condenser adjusted until all the gases have been purged from the system. When the auxiliary condenser is warm to the touch everywhere, this is an indication that steam is filling the entire condenser and little or no non-condensible gases remain. To initially purge the system of non-condensible gases may take between 15 and 30 minutes. The process should be done every few hours if extended operation of the system is required.

10. To ensure that filmwise condensation is established on the tube being tested, the following should be done:

a. Allow the apparatus to warm up to a vapor temperature of at least 3800 microvolts.

b. Raise the auxiliary coolant flow rate to 50% or 60% to cool the vapor temperature to approximately 3200 microvolts.

c. Secure coolant flow to the auxiliary condenser and allow the vapor temperature to rise to about 3700 microvolts. This forms a steam blanket over the tube.

d. Initiate coolant flow of 80% in the auxiliary condenser.

e. Adjust the coolant flowrate in the auxiliary condenser to maintain the desired temperature and pressure for the system.

11. Run the software program DRPOK by pressing the "run" key on the keyboard. The program will prompt you with questions for the necessary information it needs as follows:

· Select option ... Enter 0 for taking new data

· Select fluid ... Enter 0 for water

· Enter input mode ... Enter 0 for new data

· Enter month, date, time ... when finished press enter

· Select C_i ... 0 to find C_i and 1 to use the program value

· Give a name for the raw data set ... enter the name

· Enter the geometry code ... select plain or finned

· Enter the insert type used... select the appropriate value

· Enter the tube type ... select the appropriate value

· Select the tube enhancement used ... select the appropriate value

· Select the tube material ... enter 0 for copper

· Select the tube diameter ... enter 1 for medium

· Enter the pressure condition ... 0 vacuum, 1 atmospheric

· Select the inside correlation ... 0 Sieder-Tate, 2 Petukhov-Popov

· Select the outside theory for analysis ... 0 Nusselt or 1 Fujii

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- Select the measurement device ... 1 Quartz thermometer

- Select the output ... 0 short, 1 long

- Like to check NG concentration ... 1 yes, 2 no

- Enter flowmeter reading (%) ... enter a 2 digit number

- Connect voltage line ... flip up voltage line toggle switch on and press enter

- Disconnect voltage line ... flip voltage line toggle off and press enter

- Enter pressure gage reading ... input reading from Heise gage and press enter

- Change TCOOL rise? ... 1 yes, 2 no

- OK to store this point? ... 1 yes, 2 no

- Will there be another run? ... 1 yes, 0 no; if yes it returns to the step Like to check NG concentration for following runs

12. Prior to continuing past the question "Enter the flowmeter reading" ensure the system has been operating at steady-state conditions for at least 30 minutes.

13. **WARNING**: carefully monitor vapor pressure during warmup, especially around atmospheric pressure, to ensure an overpressure condition does not occur.

14. Vacuum runs are conducted at a heater setting of 90 volts and 1980 ± 10 microvolts on channel 40. This corresponds to $T_{sat} \approx 48°C$, and a vapor velocity of ≈ 2 m/s.

15. Atmospheric runs are performed at a heater setting of 175 volts and 4280 ± 10 microvolts on channel 40. This corresponds to $T_{sat} \approx 100°C$, and a vapor velocity of ≈ 1 m/s.

16. The viewing window can be cleared of condensation by using heated air from a blow dryer on the glass. **CAUTION**: be careful not to overheat and crack the glass.

17.   When taking readings always double check the
        flowmeter reading prior to accepting any data point.
        Also, always conduct vacuum runs prior to
        atmospheric runs because it takes too long for the
        system to cool down to the vacuum operating
        temperatures.   When trying to conduct both
        atmospheric and vacuum runs in the same day.

B.   SYSTEM SHUTDOWN PROCEDURES

When completed taking data, the system should be secured with

the following procedure:

1. Secure power to the heating elements. Turn off the
   switches on the boiler heater control panel.

2. Secure coolant flow in the auxiliary condenser. If the
   system is to remain at vacuum pressure until the next
   data run, then the auxiliary condenser can be used in
   assisting to cool the system down.

3. Secure the coolant water through the tube by securing the
   coolant pumps.

4. Secure the water flow to the coolant sump tank.

5. To return the system to atmospheric temperature, slowly
   open the vent valve on the auxiliary condenser. Ensure
   no foreign material is in the vicinity of the vent valve
   so the system does not get contaminated.

6. If   an   emergency   should   arise,   such   as   an
   overpressurization or breakage, ensure the heater power
   is secured __first!__ Let the system cool down prior to
   checking for damage.

APPENDIX C. UNCERTAINTY ANALYSIS

Uncertainties are always associated with any experimentally determined results. These uncertainties are a result of many different factors including the accuracy of measuring devices, calibration of a device, and operator experience. Although the uncertainty of a single measurement may be small, when combined with other measurements that have small uncertainties into a data reduction scheme, the effect may be to generate a large uncertainty in the final result.

The uncertainties can be estimated by using a propagation of error technique derived by Kline and McClintock [Ref. 33]. The uncertainty in a quantity, R, is a function of those variables that are used to determine that quantity. So the uncertainty of R can be represented as follows:

$$W_R = \left[\left(\frac{\partial R}{\partial x_1} W_1 \right)^2 + \left(\frac{\partial R}{\partial x_2} W_2 \right)^2 + \ldots \ldots + \left(\frac{\partial R}{\partial x_n} W_n \right)^2 \right] \qquad (C.1)$$

where:

W_R = the uncertainty of the desired dependent variable

$x_1, x_2, \ldots, x_n$ = the measured independent variables

$W_1, W_2, \ldots, W_n$ = the uncertainties of the measured variables

A complete description for the uncertainty analysis is given in Georgiadis [Ref. 34]. A program, originally designed

by Mitrou [Ref. 9], was used to calculate the uncertainties for this experiment.   Sample outputs of the uncertainty evaluations are enclosed.

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMVNC1
Pressure Condition: Vacuum
Vapor Temperature   =   48.626   (Deg C)
Water Flow Rate (%)   =   80.00
Water Velocity   =   4.32   (m/s)
Heat Flux   =   1.461E+05   (W/m^2)
Tube-metal thermal conduc.   =   385.0   (W/m.K)
Sieder-Tate constant   =   0.0179

UNCERTAINTY ANALYSIS:

        VARIABLE   PERCENT UNCERTAINTY

Mass Flow Rate, Md   0.81
Reynolds Number, Re   1.14
Heat Flux, q   1.66
Log-Mean-Tem Diff, LMTD   1.38
Wall Resistance, Rw   2.67
Overall H.T.C., Uo   2.16
Water-Side H.T.C., Hi   11.22
Vapor-Side H.T.C., Ho   11.87

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMVNC1
Pressure Condition: Vacuum
Vapor Temperature   =   48.619   (Deg C)
Water Flow Rate (%)   =   20.00
Water Velocity   =   1.16   (m/s)
Heat Flux   =   8.492E+04   (W/m^2)
Tube-metal thermal conduc.   =   385.0   (W/m.K)
Sieder-Tate constant   =   0.0179

UNCERTAINTY ANALYSIS:

        VARIABLE   PERCENT UNCERTAINTY

Mass Flow Rate, Md   3.01
Reynolds Number, Re   3.12
Heat Flux, q   3.11
Log-Mean-Tem Diff, LMTD   .64
Wall Resistance, Rw   2.67
Overall H.T.C., Uo   3.18
Water-Side H.T.C., Hi   11.46
Vapor-Side H.T.C., Ho   43.62

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMVHC1
Pressure Condition: Vacuum
Vapor Temperature   =   48.745   (Deg C)
Water Flow Rate (%)   =   80.00
Water Velocity   =   4.32   (m/s)
Heat Flux   =   1.840E+05   (W/m^2)
Tube-metal thermal conduc.   =   385.0   (W/m.K)
Sieder-Tate constant   =   0.0415

UNCERTAINTY ANALYSIS:

     VARIABLE   PERCENT UNCERTAINTY

Mass Flow Rate, Md   0.81
Reynolds Number, Re   1.15
Heat Flux, q   1.43
Log-Mean-Tem Diff, LMTD   1.10
Wall Resistance, Rw   2.67
Overall H.T.C., Uo   1.81
Water-Side H.T.C., Hi   4.92
Vapor-Side H.T.C., Ho   3.41

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMVHC1
Pressure Condition: Vacuum
Vapor Temperature   =   48.733   (Deg C)
Water Flow Rate (%)   =   20.00
Water Velocity   =   1.16   (m/s)
Heat Flux   =   1.251E+05   (W/m^2)
Tube-metal thermal conduc.   =   385.0   (W/m.K)
Sieder-Tate constant   =   0.0415

UNCERTAINTY ANALYSIS:

     VARIABLE   PERCENT UNCERTAINTY

Mass Flow Rate, Md   3.02
Reynolds Number, Re   3.13
Heat Flux, q   3.08
Log-Mean-Tem Diff, LMTD   .43
Wall Resistance, Rw   2.67
Overall H.T.C., Uo   3.11
Water-Side H.T.C., Hi   5.44
Vapor-Side H.T.C., Ho   10.09

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DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMANC1
Pressure Condition: Atmospheric (101 kPa)
Vapor Temperature   =   99.919   (Deg C)
Water Flow Rate (%)   =   80.00
Water Velocity   =   4.31   (m/s)
Heat Flux   =   4.227E+05   (W/m^2)
Tube-metal thermal conduc.   =   385.0   (W/m.K)
Sieder-Tate constant   =   0.0193

UNCERTAINTY ANALYSIS:

        VARIABLE   PERCENT UNCERTAINTY

Mass Flow Rate, Md   0.81
Reynolds Number, Re   1.16
Heat Flux, q   1.04
Log-Mean-Tem Diff, LMTD   .48
Wall Resistance, Rw   2.67
Overall H.T.C., Uo   1.14
Water-Side H.T.C., Hi   10.41
Vapor-Side H.T.C., Ho   7.38

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMANC1
Pressure Condition: Atmospheric (101 kPa)
Vapor Temperature   =   100.024   (Deg C)
Water Flow Rate (%)   =   20.00
Water Velocity   =   1.16   (m/s)
Heat Flux   =   2.757E+05   (W/m^2)
Tube-metal thermal conduc.   =   385.0   (W/m.K)
Sieder-Tate constant   =   0.0193

UNCERTAINTY ANALYSIS:

        VARIABLE   PERCENT UNCERTAINTY

Mass Flow Rate, Md   3.02
Reynolds Number, Re   3.14
Heat Flux, q   3.06
Log-Mean-Tem Diff, LMTD   .20
Wall Resistance, Rw   2.67
Overall H.T.C., Uo   3.06
Water-Side H.T.C., Hi   10.67
Vapor-Side H.T.C., Ho   27.24

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMAHC1
Pressure Condition: Atmospheric (101 kPa)
Vapor Temperature   =   99.887   (Deg C)
Water Flow Rate (%)   =   80.00
Water Velocity   =   4.31   (m/s)
Heat Flux   =   4.952E+05   (W/m^2)
Tube-metal thermal conduc. =   385.0   (W/m.K)
Sieder-Tate constant   =   0.0442

UNCERTAINTY ANALYSIS:

      VARIABLE   PERCENT UNCERTAINTY

Mass Flow Rate, Md   0.81
Reynolds Number, Re   1.17
Heat Flux, q   1.01
Log-Mean-Tem Diff, LMTD   .41
Wall Resistance, Rw   2.67
Overall H.T.C., Uo   1.09
Water-Side H.T.C., Hi   4.64
Vapor-Side H.T.C., Ho   2.01

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMAHC1
Pressure Condition: Atmospheric (101 kPa)
Vapor Temperature   =   99.879   (Deg C)
Water Flow Rate (%)   =   20.00
Water Velocity   =   1.15   (m/s)
Heat Flux   =   3.805E+05   (W/m^2)
Tube-metal thermal conduc. =   385.0   (W/m.K)
Sieder-Tate constant   =   0.0442

UNCERTAINTY ANALYSIS:

      VARIABLE   PERCENT UNCERTAINTY

Mass Flow Rate, Md   3.03
Reynolds Number, Re   3.15
Heat Flux, q   3.06
Log-Mean-Tem Diff, LMTD   .14
Wall Resistance, Rw   2.67
Overall H.T.C., Uo   3.07
Water-Side H.T.C., Hi   5.20
Vapor-Side H.T.C., Ho   7.68

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMVNT3
Pressure Condition: Vacuum
Vapor Temperature   =   48.670   (Deg C)
Water Flow Rate (%)   =   80.00
Water Velocity   =   3.63   (m/s)
Heat Flux   =   1.248E+05   (W/m^2)
Tube-metal thermal conduc.   =   21.0   (W/m.K)
Sieder-Tate constant   =   0.0179

UNCERTAINTY ANALYSIS:

        VARIABLE   PERCENT UNCERTAINTY

Mass Flow Rate, Md   0.80
Reynolds Number, Re   1.12
Heat Flux, q   2.16
Log-Mean-Tem Diff, LMTD   1.95
Wall Resistance, Rw   5.09
Overall H.T.C., Uo   2.91
Water-Side H.T.C., H_1 16.79
Vapor-Side H.T.C., Ho   17.15

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMVNT3
Pressure Condition: Vacuum
Vapor Temperature   =   48.736   (Deg C)
Water Flow Rate (%)   =   20.00
Water Velocity   =   0.97   (m/s)
Heat Flux   =   7.590E+04   (W/m^2)
Tube-metal thermal conduc.   =   21.0   (W/m.K)
Sieder-Tate constant   =   0.0179

UNCERTAINTY ANALYSIS:

        VARIABLE   PERCENT UNCERTAINTY

Mass Flow Rate, Md   3.01
Reynolds Number, Re   3.11
Heat Flux, q   3.16
Log-Mean-Tem Diff, LMTD   .86
Wall Resistance, Rw   5.09
Overall H.T.C., Uo   3.28
Water-Side H.T.C., H_1 16.95
Vapor-Side H.T.C., Ho   58.73

Heat Flux   =
DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMVHT3
Pressure Condition: Vacuum
Vapor Temperature   =   48.651   (Deg C)
Water Flow Rate (%)   =   20.00
Water Velocity   =   0.97   (m/s)
Heat Flux   =   1.082E+05   (W/m^2)
Tube-metal thermal conduc.   =   21.0   (W/m.K)
Sieder-Tate constant   =   0.0431

UNCERTAINTY ANALYSIS:

        VARIABLE   PERCENT UNCERTAINTY

Mass Flow Rate, Md   3.01
Reynolds Number, Re   3.11
Heat Flux, q   3.10
Log-Mean-Tem Diff, LMTD   .60
Wall Resistance, Rw   5.09
Overall H.T.C., Uo   3.16
Water-Side H.T.C., Hi   7.40
Vapor-Side H.T.C., Ho   12.54

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMVHT3
Pressure Condition: Vacuum
Vapor Temperature   =   48.684   (Deg C)
Water Flow Rate (%)   =   80.00
Water Velocity   =   3.63   (m/s)
Heat Flux   =   1.471E+05   (W/m^2)
Tube-metal thermal conduc.   =   21.0   (W/m.K)
Sieder-Tate constant   =   0.0431

UNCERTAINTY ANALYSIS:

        VARIABLE   PERCENT UNCERTAINTY

Mass Flow Rate, Md   0.80
Reynolds Number, Re   1.12
Heat Flux, q   1.90
Log-Mean-Tem Diff, LMTD   1.66
Wall Resistance, Rw   5.09
Overall H.T.C., Uo   2.52
Water-Side H.T.C., Hi   7.03
Vapor-Side H.T.C., Ho   6.07

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DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMANT5
Pressure Condition: Atmospheric (101 kPa)
Vapor Temperature   =   100.026   (Deg C)
Water Flow Rate (%)   =   80.00
Water Velocity   =   3.63   (m/s)
Heat Flux   =   3.632E+05   (W/m^2)
Tube-metal thermal conduc.   =   21.0   (W/m.K)
Sieder-Tate constant   =   0.0191

UNCERTAINTY ANALYSIS:

     VARIABLE   PERCENT UNCERTAINTY

Mass Flow Rate, Md   0.81
Reynolds Number, Re   1.14
Heat Flux, q   1.14
Log-Mean-Tem Diff, LMTD   .67
Wall Resistance, Rw   5.09
Overall H.T.C., Uo   1.32
Water-Side H.T.C., Hi   15.74
Vapor-Side H.T.C., Ho   11.68

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMANT5
Pressure Condition: Atmospheric (101 kPa)
Vapor Temperature   =   99.958   (Deg C)
Water Flow Rate (%)   =   20.00
Water Velocity   =   0.97   (m/s)
Heat Flux   =   2.413E+05   (W/m^2)
Tube-metal thermal conduc.   =   21.0   (W/m.K)
Sieder-Tate constant   =   0.0191

UNCERTAINTY ANALYSIS:

     VARIABLE   PERCENT UNCERTAINTY

Mass Flow Rate, Md   3.02
Reynolds Number, Re   3.12
Heat Flux, q   3.06
Log-Mean-Tem Diff, LMTD   .27
Wall Resistance, Rw   5.09
Overall H.T.C., Uo   3.07
Water-Side H.T.C., Hi   15.91
Vapor-Side H.T.C., Ho   41.47

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMAHT6
Pressure Condition: Atmospheric (101 kPa)
Vapor Temperature   =   100.020   (Deg C)
Water Flow Rate (%)   =   80.00
Water Velocity   =   3.62   (m/s)
Heat Flux   =   4.049E+05   (W/m^2)
Tube-metal thermal conduc.   =   21.0   (W/m.K)
Sieder-Tate constant   =   0.0403

UNCERTAINTY ANALYSIS:

        VARIABLE   PERCENT UNCERTAINTY

Mass Flow Rate, Md   0.81
Reynolds Number, Re   1.15
Heat Flux, q   1.10
Log-Mean-Tem Diff, LMTD   .60
Wall Resistance, Rw   5.09
Overall H.T.C., Uo   1.25
Water-Side H.T.C., Hi   7.51
Vapor-Side H.T.C., Ho   4.13

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMAHT6
Pressure Condition: Atmospheric (101 kPa)
Vapor Temperature   =   99.922   (Deg C)
Water Flow Rate (%)   =   20.00
Water Velocity   =   0.97   (m/s)
Heat Flux   =   3.120E+05   (W/m^2)
Tube-metal thermal conduc.   =   21.0   (W/m.K)
Sieder-Tate constant   =   0.0403

UNCERTAINTY ANALYSIS:

        VARIABLE   PERCENT UNCERTAINTY

Mass Flow Rate, Md   3.03
Reynolds Number, Re   3.15
Heat Flux, q   3.07
Log-Mean-Tem Diff, LMTD   .21
Wall Resistance, Rw   5.09
Overall H.T.C., Uo   3.08
Water-Side H.T.C., Hi   7.87
Vapor-Side H.T.C., Ho   11.47

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APPENDIX D. DATA RUNS

The names of the data files are listed in Tables 2 through 13 in Chapter 5. The data files presented in this appendix have been reprocessed using the Petukhov-Popov [Ref. 29] form of the inside heat transfer correlation. The data have been printed out in the short form format.

```
NOTE: Program name : DRPOK
      Data taken by                : O'KEEFE
      This analysis done on file : FONMAHT1
      This analysis includes end-fin effect
      Thermal conductivity      = 21.0 (W/m.K)
      Inside diameter, Di       = 13.86 (mm)
      Outside diameter, Do      = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement    : SMOOTH TUBE
      Tube material       : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho


C1 (based on Petukhov-Popov)    =  2.3715
Alpha (based on Nusselt (Tdel)) =  0.7801
Enhancement (q)                     =   .993
Enhancement (Del-T)                 =   .972
```

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.66	5.352E+03	9.727E+03	4.334E+05	44.55	100.11
2	3.21	5.297E+03	9.885E+03	4.242E+05	42.91	99.96
3	2.76	5.210E+03	1.003E+04	4.132E+05	41.19	99.97
4	2.31	5.054E+03	1.006E+04	3.963E+05	39.45	100.05
5	1.87	4.895E+03	1.030E+04	3.792E+05	36.81	100.01
6	1.42	4.639E+03	1.058E+04	3.546E+05	33.58	100.04
7	0.97	4.276E+03	1.128E+04	3.220E+05	28.55	100.07
8	1.42	4.619E+03	1.039E+04	3.486E+05	33.54	100.00
9	1.86	4.874E+03	1.011E+04	3.675E+05	36.35	99.94
10	2.30	5.091E+03	1.008E+04	3.845E+05	38.16	100.06
11	2.75	5.232E+03	9.967E+03	3.944E+05	39.57	99.99
12	3.19	5.339E+03	9.860E+03	4.014E+05	40.71	99.95
13	3.63	5.391E+03	9.682E+03	4.055E+05	41.64	100.05

```
Least-Squares Line for Ho vs q curve:
  Slope      = -3.1043E-01
  Intercept  =  7.7397E+05

Least-squares line for q = a*delta-T^b
  a =  2.5179E+04
  b =  7.5000E-01


NOTE: 13 data points were stored in file FONMAHT1

NOTE: 13 K-q pairs were stored in data file
```

NOTE: Program name : DRPOK
      Data taken by   : O'KEEFE
      This analysis done on file : FONMAHT2
      This analysis includes end-fin effect
      Thermal conductivity   = 21.0 (W/m.K)
      Inside diameter, D_i = 13.66 (mm)
      Outside diameter, D_o = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement   : SMOOTH TUBE
      Tube material   : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

C_i (based on Petukhov-Popov)   = 2.3833
Alpha (based on Nusselt (Tdel)) = 0.7740
Enhancement (q)   = .953
Enhancement (Del-T)   = .965

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tof (C)	Ts (C)
1	3.65	5.332E+03	9.587E+03	4.209E+05	43.91	100.09
2	3.20	5.312E+03	9.653E+03	4.147E+05	42.08	99.94
3	2.75	5.197E+03	9.887E+03	4.018E+05	40.54	100.05
4	2.31	5.069E+03	1.000E+04	3.875E+05	38.74	100.09
5	1.42	4.657E+03	1.049E+04	3.474E+05	33.12	100.02
6	0.97	4.290E+03	1.109E+04	3.150E+05	28.40	99.91
7	1.41	4.675E+03	1.054E+04	3.459E+05	32.83	100.03
8	1.86	4.940E+03	1.029E+04	3.655E+05	35.51	99.98
9	2.30	5.114E+03	1.008E+04	3.785E+05	37.54	100.01
10	2.74	5.245E+03	9.944E+03	3.882E+05	39.04	100.03
11	3.18	5.329E+03	9.763E+03	3.939E+05	40.28	100.05
12	3.62	5.456E+03	9.657E+03	4.022E+05	40.60	99.93
13	3.62	5.448E+03	9.803E+03	4.006E+05	40.76	99.94

Least-Squares Line for Ho vs q curve:
   Slope   = -3.1793E-01
   Intercept = 7.8191E-05

Least-squares line for q = a+delta-T b
   a = 2.4999E-04
   b = 7.5000E-01

NOTE: 13 data points were stored in file FONMAHT2

NOTE: 13 x-y pairs were stored in data file

```
NOTE: Program name : DRPOK
      Data taken by              : O'KEEFE
      This analysis done on file : FONMAHT3
      This analysis includes end-fin effect
      Thermal conductivity      =  21.0 (W/m.K)
      Inside diameter, Di       = 13.36 (mm)
      Outside diameter, Do      = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement   : SMOOTH TUBE
      Tube material      : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho
```

C_i (based on Petukhov-Popov)   = 2.3923
Alpha (based on Nusselt (Tdel)) = 0.7551
Enhancement (q)   =   .922
Enhancement (Del-T)   =   .941

Data #	Vw (m/s)	Uc (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.62	5.411E+03	9.701E+03	4.000E+05	41.23	99.93
2	3.18	5.316E+03	9.717E+03	3.913E+05	40.27	100.01
3	2.74	5.185E+03	9.693E+03	3.796E+05	39.16	100.02
4	2.29	5.048E+03	9.766E+03	3.674E+05	37.63	100.05
5	1.85	4.872E+03	9.904E+03	3.520E+05	35.54	99.93
6	1.41	4.633E+03	1.017E+04	3.322E+05	32.68	99.96
7	1.19	4.494E+03	1.050E+04	3.205E+05	30.53	100.00
8	0.97	4.322E+03	1.105E+04	3.063E+05	27.72	100.08

```
Least-Squares Line for Ho vs q curve:
   Slope     = -3.1603E-01
   Intercept =  7.7848E+05

Least-squares line for q = a*delta-T^b
   a =  2.4500E-04
   b =  7.5000E-01


NOTE: 08 data points were stored in file FONMAHT3

NOTE: 08 X-Y pairs were stored in data file
```

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```
NOTE: Program name : DRPOK
      Data taken by                : O'KEEFE
      This analysis done on file : FONMAHT4
      This analysis includes end-fin effect
      Thermal conductivity      = 21.0 (W/m.K)
      Inside diameter, Di        = 13.96 (mm)
      Outside diameter, Do       = 15.95 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement   : SMOOTH TUBE
      Tube material      : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho
```

```
Ci (based on Petukhov-Popov)     =   2.4099
Alpha (based on Nusselt (Tdel)) =   0.7464
Enhancement (q)                  =    .911
Enhancement (Del-T)              =    .933
```

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C
1	0.97	4.236E+03	1.079E+04	3.171E+05	29.40	100.04
2	1.42	4.556E+03	9.950E+03	3.427E+05	34.44	100.03
3	1.64	4.702E+03	9.843E+03	3.517E+05	35.74	99.95
4	2.08	4.919E+03	9.698E+03	3.679E+05	37.92	99.98
5	2.52	5.108E+03	9.703E+03	3.809E+05	39.26	100.03
6	2.96	5.221E+03	9.537E+03	3.881E+05	40.44	100.04
7	3.40	5.329E+03	9.570E+03	3.936E+05	41.13	99.99
8	3.62	5.358E+03	9.505E+03	3.946E+05	41.52	100.03
9	3.18	5.295E+03	9.612E+03	3.874E+05	40.30	100.10
10	2.73	5.186E+03	9.657E+03	3.774E+05	39.07	100.03
11	2.29	5.010E+03	9.583E+03	3.627E+05	37.35	100.23
12	1.63	4.739E+03	9.650E+03	3.398E+05	34.50	100.03
13	0.97	4.236E+03	1.072E+04	3.025E+05	29.21	100.03

```
Least-Squares Line for Ho vs q curve:
  Slope      = -3.1839E-01
  Intercept  =  7.7639E+05

Least-squares line for q = a*delta-T^b
  a =  2.4222E+04
  b =  7.5000E-01


NOTE: 13 data points were stored in file FONMAHT4

NOTE: 13 x-y pairs were stored in data file
```

```
NOTE: Program name : DRPOK
      Data taken by                : O'KEEFE
      This analysis done on file : FONMAHTS
      This analysis includes end-fin effect
      Thermal conductivity     =  21.0 (W/m.K)
      Inside diameter, Di       = 13.36 (mm)
      Outside diameter, Do      = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement   : SMOOTH TUBE
      Tube material      : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho
```

Ci (based on Petukhov-Popov)   = 2.2011
Alpha (based on Nusselt (Tdel)) = 0.7700
Enhancement (q)   =   .947
Enhancement (Del-T)   =   .960

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.64	5.268E+03	9.574E+03	4.057E+05	42.38	99.90
2	3.19	5.273E+03	9.935E+03	4.002E+05	40.23	99.96
3	2.74	5.200E+03	1.014E+04	3.896E+05	38.41	99.95
4	2.30	5.035E+03	1.015E+04	3.717E+05	36.62	99.92
5	1.85	4.822E+03	1.018E+04	3.509E+05	34.47	100.00
6	1.41	4.599E+03	1.064E+04	3.313E+05	31.14	99.99
7	0.97	4.218E+03	1.132E+04	2.994E+05	26.44	100.05
8	1.19	4.423E+03	1.064E+04	3.152E+05	29.08	99.97
9	1.63	4.770E+03	1.058E+04	3.426E+05	32.40	100.02
10	2.07	4.992E+03	1.034E+04	3.595E+05	34.77	99.93
11	2.51	5.159E+03	1.020E+04	3.730E+05	36.56	100.01
12	2.95	5.253E+03	9.979E+03	3.800E+05	38.28	99.92
13	3.39	5.333E+03	9.832E+03	3.862E+05	39.23	99.96
14	3.61	5.364E+03	9.860E+03	3.908E+05	39.63	100.27

Least-Squares Line for Ho vs q curve:
  Slope   = -3.1391E-01
  Intercept = 7.7964E+05

Least-squares line for q = a*delta-T^b
  a = 2.4990E+04
  b = 7.5000E-01

NOTE: Program name : DRPOK
       Data taken by   : O'KEEFE
       This analysis done on file : FONMAHT6
       This analysis includes end-fin effect
       Thermal conductivity   = 21.0 (W/m.K)
       Inside diameter, D_i = 13.86 (mm)
       Outside diameter, Do   = 15.85 (mm)
       This analysis uses the QUARTZ THERMOMETER readings
       Modified Petukhov-Popov coefficient   = 1.0000
       Using HEATEX insert inside tube
       Tube Enhancement   : SMOOTH TUBE
       Tube material   : TITANIUM
       Pressure condition : ATMOSPHERIC
       Nusselt theory is used for Ho

C_i (based on Petukhov-Popov)   =   2.5406
Alpha (based on Nusselt (Tdel)) =   0.7758
Enhancement (q)   =   .956
Enhancement (Del-T)   =   .967

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C
1	3.62	5.523E+03	9.871E+03	4.049E+05	41.01	100.02
2	3.18	5.441E+03	9.923E+03	3.969E+05	40.00	100.05
3	2.73	5.369E+03	1.010E+04	3.892E+05	38.54	99.99
4	2.29	5.247E+03	1.023E+04	3.765E+05	36.91	99.90
5	2.07	5.133E+03	1.016E+04	3.680E+05	36.21	99.96
6	1.41	4.806E+03	1.064E+04	3.410E+05	32.06	99.75
7	0.97	4.458E+03	1.121E+04	3.120E+05	27.93	99.82
8	1.41	4.816E+03	1.053E+04	3.411E+05	32.20	99.92
9	1.85	5.089E+03	1.044E+04	3.630E+05	34.76	99.99
10	2.29	5.230E+03	1.015E+04	3.744E+05	35.89	99.98
11	2.51	5.320E+03	1.017E+04	3.806E+05	37.44	99.94
12	2.73	5.411E+03	1.022E+04	3.876E+05	37.93	99.97
13	3.17	5.461E+03	9.950E+03	3.920E+05	39.36	100.04

Least-Squares Line for Ho vs q curve:
   Slope   = -3.0354E-01
   Intercept = 7.7703E+05

Least-squares line for q = a*delta-T^b
   a = 2.6178E+04
   b = 7.5000E-01

NOTE: 13 data points were stored in file FONMAHT6

NOTE: 13 X-Y pairs were stored in data file

```
NOTE: Program name : ORPOK
      Data taken by                : O'KEEFE
      This analysis done on file : FONMAHT7
      This analysis includes end-fin effect
      Thermal conductivity       =  21.0 (W/m.K)
      Inside diameter, Di         = 13.85 (mm)
      Outside diameter, Do        = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement   : SMOOTH TUBE
      Tube material      : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho
```

C_1 (based on Petukhov-Popov)   = 2.5109
Alpha (based on Nusselt (Tdel)) = 0.7924
Enhancement (q)   =   .983
Enhancement (Del-T)   =   .987

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C)
1	3.64	5.512E+03	9.985E+03	4.296E+05	42.93	100.05
2	3.19	5.415E+03	9.976E+03	4.142E+05	41.52	99.94
3	2.75	5.348E+03	1.019E+04	4.048E+05	39.79	99.90
4	2.52	5.309E+03	1.030E+04	3.998E+05	38.81	100.03
5	2.30	5.239E+03	1.037E+04	3.923E+05	37.84	99.94
6	2.08	5.150E+03	1.041E+04	3.847E+05	36.94	100.05
7	1.86	5.037E+03	1.043E+04	3.742E+05	35.37	99.91
8	1.41	4.791E+03	1.073E+04	3.538E+05	32.97	99.96
9	0.97	4.451E+03	1.157E+04	3.252E+05	29.10	100.06
10	1.41	4.799E+03	1.078E+04	3.551E+05	32.95	100.04
11	1.86	5.042E+03	1.045E+04	3.752E+05	35.99	100.03
12	2.30	5.231E+03	1.032E+04	3.896E+05	37.76	99.93
13	2.74	5.372E+03	1.022E+04	4.007E+05	39.20	99.93

```
Least-Squares Line for Ho vs q curve:
   Slope      = -3.1602E-01
   Intercept  =  7.8408E+05

Least-squares line for q = a*delta-T b
   a =  2.5669E+04
   b =  7.5000E-01


NOTE: 13 data points were stored in file FONMAHT7

NOTE: 13 X-Y pairs were stored in data file
```

NOTE: Program name : DRPOK
      Data taken by   : O'KEEFE
      This analysis done on file : FONMANT1
      This analysis includes end-fin effect
      Thermal conductivity   = 21.0 (W/m.K)
      Inside diameter, Di   = 13.66 (mm)
      Outside diameter, Do   = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement   : SMOOTH TUBE
      Tube material   : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)   = 1.2114
Alpha (based on Nusselt (Tdel)) = 0.7504
Enhancement (q)   =   .941
Enhancement (Del-T)   =   .955

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C
1	2.74	4.483E+03	1.050E+04	3.315E+05	31.56	100.02
2	2.51	4.399E+03	1.053E+04	3.200E+05	30.39	99.69
3	2.29	4.273E+03	1.051E+04	3.091E+05	29.42	100.05
4	2.07	4.147E+03	1.052E+04	2.971E+05	28.25	99.99
5	1.85	4.006E+03	1.056E+04	2.851E+05	26.95	99.90
6	1.41	3.687E+03	1.106E+04	2.609E+05	23.60	99.93
7	0.97	3.293E+03	1.293E+04	2.304E+05	17.81	99.36
8	1.41	3.687E+03	1.101E+04	2.594E+05	23.57	99.99
9	1.85	4.030E+03	1.066E+04	2.837E+05	26.60	99.95
10	2.07	4.183E+03	1.064E+04	2.949E+05	27.72	100.19
11	2.30	4.295E+03	1.076E+04	3.161E+05	29.33	99.31
12	2.74	4.450E+03	1.042E+04	3.356E+05	32.21	100.23
13	3.19	4.623E+03	1.037E+04	3.493E+05	33.71	99.65

Least-Squares Line for Ho vs q curve:
  Slope   = -2.6012E-01
  Intercept = 7.6036E+05

Least-squares line for q = a*delta-T b
  a = 2.4594E-04
  b = 7.5000E-01

NOTE: 13 data points were stored in file FONMANT1

NOTE: 13 X-Y pairs were stored in data file

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```
NOTE: Program name : DRPOK
      Data taken by                : O'KEEFE
      This analysis done on file : FONMANT2
      This analysis includes end-fin effect
      Thermal conductivity      = 21.0 (W/m.K)
      Inside diameter, Di        = 13.85 (mm)
      Outside diameter, Do       = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement   : SMOOTH TUBE
      Tube material      : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho
```

C_i (based on Petukhov-Popov)   = 1.1849
Alpha (based on Nusselt (Tdel)) = 0.7603
Enhancement (q)   =   .957
Enhancement (Del-T)   =   .968

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.65	4.668E+03	1.022E+04	3.713E+05	36.34	99.99
2	3.20	4.572E+03	1.046E+04	3.586E+05	34.26	100.01
3	2.75	4.426E+03	1.064E+04	3.421E+05	32.15	100.01
4	2.31	4.226E+03	1.080E+04	3.226E+05	29.86	100.04
5	1.86	3.933E+03	1.073E+04	2.958E+05	27.57	99.94
6	1.41	3.615E+03	1.107E+04	2.636E+05	23.64	100.02
7	0.97	3.263E+03	1.396E+04	2.382E+05	17.06	99.99
8	1.19	3.387E+03	1.118E+04	2.454E+05	21.95	99.95
9	0.97	3.209E+03	1.261E+04	2.286E+05	18.15	99.93
10	1.19	3.399E+03	1.112E+04	2.424E+05	21.80	99.99
11	1.41	3.647E+03	1.115E+04	2.608E+05	23.39	99.99
12	1.86	4.000E+03	1.095E+04	2.868E+05	26.43	99.91
13	2.07	4.154E+03	1.092E+04	2.988E+05	27.52	100.11
14	2.29	4.286E+03	1.079E+04	3.082E+05	28.57	99.96
15	2.51	4.410E+03	1.077E+04	3.167E+05	29.40	99.97
16	2.73	4.530E+03	1.081E+04	3.248E+05	30.04	99.91

```
Least-Squares Line for Ho vs q curve:
   Slope      = -2.5701E-01
   Intercept  =  7.5050E-05

Least-squares line for q = a*delta-T^b
   a =  2.5129E+04
   b =  7.3000E-01


NOTE: 16 data points were stored in file FONMANT2

NOTE: 16 X-Y pairs were stored in data file
```

NOTE: Program name : DRPOK
      Data taken by   : O'KEEFE
      This analysis done on file : FONMANT3
      This analysis includes end-fin effect
      Thermal conductivity   = 21.0 (W/m.K)
      Inside diameter, Di   = 13.86 (mm)
      Outside diameter, Do   = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement   : SMOOTH TUBE
      Tube material   : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

C_i (based on Petukhov-Popov)   =   1.1896
Alpha (based on Nusselt (Toel)) =   0.7650
Ennancement (q)   =   .965
Enhancement (Del-T)   =   .974

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C
1	0.97	3.230E+03	1.310E+04	2.269E+05	17.32	99.88
2	1.41	3.652E+03	1.136E+04	2.595E+05	22.36	100.05
3	1.63	3.837E+03	1.113E+04	2.730E+05	24.53	99.92
4	1.85	4.008E+03	1.104E+04	2.857E+05	25.89	99.97
5	2.07	4.143E+03	1.087E+04	2.959E+05	27.21	99.96
6	2.29	4.236E+03	1.057E+04	3.028E+05	28.64	99.93
7	2.51	4.424E+03	1.096E+04	3.165E+05	28.67	99.93
8	2.73	4.513E+03	1.082E+04	3.229E+05	29.63	99.92
9	2.95	4.627E+03	1.088E+04	3.308E+05	30.41	99.93
10	3.17	4.745E+03	1.101E+04	3.394E+05	30.82	99.94
11	3.61	4.815E+03	1.055E+04	3.457E+05	32.76	100.01
12	2.29	4.291E+03	1.092E+04	3.070E+05	25.12	100.04

Least-Squares Line for Ho vs q curve:
   Slope   = -2.4792E-01
   Intercept = 7.5635E+05

Least-squares line for q = a*delta-T b
   a = 2.5250E-04
   b = 7.5000E-01

NOTE: 12 data points were stored in file FONMANT3

NOTE: 12 x-y pairs were stored in data file

NOTE: Program name : DRPOK
      Data taken by   : O'KEEFE
      This analysis done on file : FONMANT4
      This analysis includes end-fin effect
      Thermal conductivity   = 21.0 (W/m.K)
      Inside diameter, Di   = 13.86 (mm)
      Outside diameter, Do   = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient = 1.0000
      Using no insert inside tube
      Tube Enhancement   : SMOOTH TUBE
      Tube material   : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)   = 1.1611
Alpha (based on Nusselt (Tdel)) = 0.7548
Enhancement (q)   = .965
Enhancement (Del-T)   = .974

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C)
1	3.62	4.778E+03	1.036E+04	3.479E+05	33.59	100.00
2	0.97	3.192E+03	1.259E+04	2.299E+05	16.26	100.06
3	1.85	3.969E+03	1.083E+04	2.910E+05	26.87	99.97
4	2.30	4.246E+03	1.072E+04	3.133E+05	29.23	100.02
5	2.74	4.465E+03	1.064E+04	3.317E+05	31.19	100.21
6	3.18	4.648E+03	1.059E+04	3.453E+05	32.59	99.99
7	3.63	4.792E+03	1.047E+04	3.552E+05	33.99	99.96
8	3.62	4.755E+03	1.030E+04	3.525E+05	34.21	100.34
9	3.18	4.663E+03	1.061E+04	3.433E+05	32.36	100.24
10	2.74	4.506E+03	1.079E+04	3.294E+05	30.52	99.99
11	2.29	4.287E+03	1.077E+04	3.110E+05	28.88	100.01
12	1.85	3.971E+03	1.077E+04	2.895E+05	26.89	100.09
13	1.41	3.628E+03	1.116E+04	2.626E+05	23.54	99.92
14	0.97	3.193E+03	1.266E+04	2.305E+05	16.21	99.99

Least-Squares Line for Ho vs q curve:
   Slope   = -2.5778E-01
   Intercept = 7.6096E+05

Least-squares line for q = a*delta-T^b
   a = 2.5144E+04
   b = 7.5000E-01

NOTE: 14 data points were stored in file FONMANT4

NOTE: 14 X-Y pairs were stored in data file

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```
NOTE: Program name : DRPOK
      Data taken by              : O'KEEFE
      This analysis done on file : FONMANT5
      This analysis includes end-fin effect
      Thermal conductivity       = 21.0 (W/m.K)
      Inside diameter, Di        = 13.86 (mm)
      Outside diameter, Do       = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement   : SMOOTH TUBE
      Tube material      : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho


Ci (based on Petukhov-Popov)     =  1.2370
Alpha (based on Nusselt (Tdel))  =  0.7863
Enhancement (q)                  =  1.001
Enhancement (Del-T)              =  1.001


Data    Vw       Uo          Ho          Qp          Tcf      Ts
 #     (m/s)   (W/m^2-K)   (W/m^2-K)    (W/m^2)      (C)      (C
 1     3.63    4.877E+03   1.061E+04   3.632E+05    34.25   100.03
 2     3.18    4.755E+03   1.076E+04   3.513E+05    32.64    99.97
 3     2.74    4.591E+03   1.093E+04   3.394E+05    31.06   100.00
 4     2.30    4.374E+03   1.107E+04   3.234E+05    29.22   100.00
 5     1.86    4.083E+03   1.115E+04   3.021E+05    27.09   100.02
 6     1.41    3.723E+03   1.148E+04   2.750E+05    23.95   100.00
 7     0.97    3.287E+03   1.309E+04   2.413E+05    18.43    99.96
 8     1.41    3.720E+03   1.148E+04   2.755E+05    23.99    99.97
 9     0.97    3.283E+03   1.308E+04   2.416E+05    18.47    99.95
10     1.86    4.081E+03   1.120E+04   3.040E+05    27.15   100.01
11     2.30    4.390E+03   1.117E+04   3.267E+05    29.26    99.99
12     2.74    4.572E+03   1.091E+04   3.436E+05    31.49   100.04
13     3.19    4.748E+03   1.081E+04   3.573E+05    33.04   100.05
14     3.63    4.873E+03   1.064E+04   3.664E+05    34.45    99.95
15     2.30    4.355E+03   1.103E+04   3.263E+05    29.57   100.03
16     0.97    3.256E+03   1.273E+04   2.411E+05    18.66    99.94


Least-Squares Line for Ho vs q curve:
  Slope       = -2.5021E-01
  Intercept   =  7.6397E+05

Least-squares line for q = a+delta-T^b
  a =  2.5924E+04
  b =  7.5000E-01



NOTE: 16 data points were stored in file FONMANT5

NOTE: 16 X-Y pairs were stored in data file


                              118
```

```
NOTE: Program name : DRPOK
      Data taken by                : O'KEEFE
      This analysis done on file : FONMVHT3
      This analysis includes end-fin effect
      Thermal conductivity      =  21.0 (W/m.K)
      Inside diameter, Di       = 13.66 (mm)
      Outside diameter, Do      = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement    : SMOOTH TUBE
      Tube material       : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho
```

Ci (based on Petukhov-Popov)   =   2.5472
Alpha (based on Nusselt (Tdel)) =   0.7483
Enhancement (q)   =   .824
Enhancement (Del-T)   =   .885

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C)
1	0.97	4.574E+03	1.251E+04	1.062E+05	8.65	48.65
2	1.64	5.049E+03	1.115E+04	1.231E+05	11.04	48.64
3	2.08	5.282E+03	1.096E+04	1.303E+05	11.99	48.68
4	2.52	5.490E+03	1.098E+04	1.362E+05	12.40	48.67
5	2.97	5.652E+03	1.099E+04	1.407E+05	12.80	48.67
6	3.41	5.797E+03	1.105E+04	1.446E+05	13.08	48.65
7	3.63	5.871E+03	1.113E+04	1.471E+05	13.22	48.68
8	3.63	5.815E+03	1.093E+04	1.457E+05	13.33	48.70
9	3.41	5.774E+03	1.098E+04	1.445E+05	13.16	48.72
10	2.97	5.690E+03	1.114E+04	1.412E+05	12.67	48.63
11	2.08	5.275E+03	1.092E+04	1.297E+05	11.87	48.67
12	1.64	5.052E+03	1.116E+04	1.232E+05	11.04	48.73
13	1.19	4.698E+03	1.142E+04	1.130E+05	9.89	48.69
14	0.97	4.474E+03	1.130E+04	1.060E+05	9.99	48.62

Least-Squares Line for Ho vs q curve:
  Slope   = -3.1158E-01
  Intercept = 5.9173E+05

Least-squares line for q = a*delta-T^b
  a = 2.0703E+04
  b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVHT3

NOTE: 14 X-Y pairs were stored in data file

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NOTE: Program name : DRPOK
       Data taken by   : O'KEEFE
       This analysis done on file : FONMVHT4
       This analysis includes end-fin effect
       Thermal conductivity   = 21.0 (W/m.K)
       Inside diameter, D_i = 13.86 (mm)
       Outside diameter, Do   = 15.85 (mm)
       This analysis uses the QUARTZ THERMOMETER readings
       Modified Petukhov-Popov coefficient   = 1.0000
       Using HEATEX insert inside tube
       Tube Enhancement   : SMOOTH TUBE
       Tube material   : TITANIUM
       Pressure condition : VACUUM
       Nusselt theory is used for Ho

C_i (based on Petukhov-Popov)   =   2.2780
Alpha (based on Nusselt (Tdel)) =   0.7900
Enhancement (q)   =   .985
Enhancement (Del-T)   =   .913

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C
1	3.64	5.867E+03	1.159E+04	1.505E+05	12.98	48.68
2	3.19	5.759E+03	1.167E+04	1.456E+05	12.48	43.65
3	2.75	5.583E+03	1.158E+04	1.392E+05	12.01	48.63
4	2.52	5.559E+03	1.189E+04	1.380E+05	11.60	48.67
5	2.30	5.421E+03	1.175E+04	1.339E+05	11.39	48.68
6	2.08	5.290E+03	1.165E+04	1.299E+05	11.14	48.67
7	1.86	5.203E+03	1.198E+04	1.273E+05	10.62	48.64
8	1.42	4.906E+03	1.242E+04	1.192E+05	9.59	48.70
9	0.97	4.453E+03	1.326E+04	1.066E+05	8.04	48.74
10	1.42	4.907E+03	1.243E+04	1.196E+05	9.62	48.65
11	1.86	5.161E+03	1.178E+04	1.274E+05	10.32	48.67
12	2.30	5.424E+03	1.178E+04	1.350E+05	11.46	48.68
13	2.53	5.530E+03	1.177E+04	1.380E+05	11.73	48.69
14	2.75	5.607E+03	1.169E+04	1.403E+05	12.01	48.74
15	3.19	5.731E+03	1.154E+04	1.435E+05	12.43	48.68
16	3.63	5.831E+03	1.143E+04	1.464E+05	12.91	48.68

Least-Squares Line for Ho vs q curve:
   Slope   = -3.2707E-01
   Intercept = 5.8591E+05

Least-squares line for q = a*delta-T^b
   a = 2.1743E+04
   b = 7.5000E-01

NOTE: 16 data points were stored in file FONMVHT4

NOTE: 16 X-Y pairs were stored in data file

```
NOTE: Program name : ORPOK
      Data taken by              : O'KEEFE
      This analysis done on file : FONMVHTS
      This analysis includes end-fin effect
      Thermal conductivity      =  21.0 (W/m.K)
      Inside diameter, Di       = 13.86 (mm)
      Outside diameter, Do      = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement   : SMOOTH TUBE
      Tube material      : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho
```

Ci (based on Petukhov-Popov)   = 2.4221
Alpha (based on Nusselt (Tdel)) = 0.7627
Enhancement (q)   =   .845
Enhancement (Del-T)   =   .881

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	0.97	4.402E+03	1.202E+04	1.082E+05	9.00	48.67
2	1.42	4.872E+03	1.165E+04	1.215E+05	10.43	48.64
3	1.86	5.173E+03	1.141E+04	1.301E+05	11.41	48.65
4	2.08	5.274E+03	1.125E+04	1.331E+05	11.83	48.72
5	2.30	5.395E+03	1.128E+04	1.362E+05	12.07	48.70
6	2.53	5.422E+03	1.097E+04	1.366E+05	12.45	48.65
7	2.75	5.510E+03	1.098E+04	1.395E+05	12.71	48.75
8	3.19	5.676E+03	1.105E+04	1.440E+05	13.02	48.78
9	3.64	5.745E+03	1.087E+04	1.461E+05	13.44	48.78
10	3.19	5.741E+03	1.130E+04	1.453E+05	12.86	48.82
11	2.75	5.600E+03	1.133E+04	1.404E+05	12.39	48.69
12	2.30	5.390E+03	1.124E+04	1.347E+05	11.96	48.73
13	2.08	5.317E+03	1.143E+04	1.324E+05	11.59	48.72
14	1.86	5.202E-03	1.152E+04	1.296E+05	11.24	48.80
15	1.42	4.874E-03	1.162E+04	1.198E+05	10.31	48.74

Least-Squares Line for Ho vs q curve:
   Slope   = -3.1155E-01
   Intercept = 5.8244E+05

Least-squares line for q = a*delta-T^b
   a = 2.0955E+04
   b = 7.5000E-01

NOTE: 15 data points were stored in file FONMVHTS

NOTE: 15 X-Y pairs were stored in data file

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NOTE: Program name : DRPOK
      Data taken by   : O'KEEFE
      This analysis done on file : FONMVNT2
      This analysis includes end-fin effect
      Thermal conductivity   = 21.0 (W/m.K)
      Inside diameter, Di   = 13.86 (mm)
      Outside diameter, Do   = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement   : SMOOTH TUBE
      Tube material   : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)   =   1.0922
Alpha (based on Nusselt (Tdel)) = 0.8215
Enhancement (q)   =   .378
Enhancement (Del-T)   =   .907

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C
1	3.63	5.038E+03	1.269E+04	1.244E+05	9.81	48.66
2	3.19	4.901E+03	1.307E+04	1.206E+05	9.23	48.70
3	2.74	4.702E+03	1.334E+04	1.155E+05	8.66	48.76
4	2.52	4.581E+03	1.346E+04	1.122E+05	8.34	48.74
5	2.30	4.450E+03	1.363E+04	1.089E+05	7.99	48.77
6	2.08	4.267E+03	1.348E+04	1.045E+05	7.75	48.82
7	1.86	4.081E+03	1.353E+04	1.003E+05	7.41	48.66
8	1.42	3.698E+03	1.447E+04	9.028E+04	6.24	48.65
9	0.97	3.076E+03	1.429E+04	7.465E+04	5.23	48.70
10	1.86	4.119E+03	1.396E+04	1.015E+05	7.27	48.70
11	2.75	4.739E+03	1.367E+04	1.178E+05	8.61	48.79
12	3.63	5.059E+03	1.283E+04	1.258E+05	9.61	48.74

Least-Squares Line for Ho vs q curve:
  Slope   = -2.5424E-01
  Intercept = 5.7915E+05

Least-squares line for q = a*delta-T^b
  a = 2.2680E+04
  b = 7.5000E-01

NOTE: 12 data points were stored in file FONMVNT2

NOTE: 12 X-Y pairs were stored in data file

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```
NOTE: Program name : DRPOK
      Data taken by                : O'KEEFE
      This analysis done on file : FONMVNT3
      This analysis includes end-fin effect
      Thermal conductivity      =  21.0 (W/m.K)
      Inside diameter, Di       = 13.86 (mm)
      Outside diameter, Do      = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement    : SMOOTH TUBE
      Tube material       : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho
```

C₁ (based on Petukhov-Popov)   = 1.0775
Alpha (based on Nusselt (Tdel)) = 0.7876
Enhancement (q)   =   .830
Enhancement (Del-T)   =   .869

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.63	4.954E+03	1.235E+04	1.248E+05	10.11	48.67
2	3.19	4.794E+03	1.255E+04	1.204E+05	9.59	48.64
3	2.75	4.586E+03	1.271E+04	1.152E+05	9.07	48.66
4	2.30	4.325E+03	1.284E+04	1.086E+05	8.46	48.73
5	1.86	3.990E+03	1.291E+04	9.969E+04	7.72	48.70
6	1.42	3.629E+03	1.394E+04	8.986E+04	6.45	48.63
7	0.97	3.079E+03	1.508E+04	7.590E+04	5.03	48.74
8	1.42	3.643E+03	1.416E+04	9.041E+04	6.39	48.62
9	0.97	3.061E+03	1.464E+04	7.506E+04	5.13	48.63
10	2.30	4.305E+03	1.268E+04	1.080E+05	8.51	48.60
11	2.75	4.555E+03	1.248E+04	1.146E+05	9.18	48.67
12	3.19	4.767E+03	1.237E+04	1.200E+05	9.70	48.69
13	3.63	4.946E+03	1.229E+04	1.245E+05	10.13	48.73
14	3.19	4.768E+03	1.237E+04	1.193E+05	9.65	48.67
15	3.63	4.977E+03	1.248E+04	1.248E+05	10.00	48.71
16	2.75	4.568E+03	1.255E+04	1.140E+05	9.09	48.73
17	2.30	4.323E+03	1.278E+04	1.072E+05	8.36	48.63
18	1.86	3.981E+03	1.278E+04	9.859E+04	7.72	48.71
19	1.42	3.636E+03	1.397E+04	8.922E+04	6.39	48.67
20	0.97	3.062E+03	1.455E+04	7.448E+04	5.12	48.70

Least-Squares Line for Ho vs q curve:
  Slope   = -2.8863E-01
  Intercept = 5.3155E+05

Least-squares line for q = a*delta-T^b
  a = 2.1947E+04
  b = 7.5000E-01

NOTE: 20 data points were stored in file FONMVNT3

NOTE: 20 X-Y pairs were stored in data file

```
NOTE: Program name : DRPOK
      Data taken by              : O'KEEFE
      This analysis done on file : FONMVNT4
      This analysis includes end-fin effect
      Thermal conductivity      =  21.0 (W/m.K)
      Inside diameter, Di       = 13.86 (mm)
      Outside diameter, Do      = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement   : SMOOTH TUBE
      Tube material      : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho
```

Cᵢ (based on Petukhov-Popov)   = 1.0742
Alpha (based on Nusselt (Tdel)) = 0.8455
Enhancement (q)   =   .912
Enhancement (Del-T)   =   .933

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C)
1	3.63	5.095E+03	1.328E+04	1.274E+05	9.59	48.68
2	3.19	4.910E+03	1.340E+04	1.222E+05	9.12	48.63
3	2.75	4.749E+03	1.407E+04	1.183E+05	8.41	48.66
4	2.30	4.459E+03	1.413E+04	1.110E+05	7.86	48.66
5	1.86	4.166E+03	1.502E+04	1.037E+05	6.91	48.70
6	1.42	3.726E+03	1.559E+04	9.234E+04	5.92	48.67
7	0.97	3.166E+03	1.764E+04	7.792E+04	4.42	48.72
8	1.42	3.719E+03	1.550E+04	9.256E+04	5.97	48.67
9	0.97	3.161E+03	1.747E+04	7.765E+04	4.45	48.65
10	1.86	4.133E+03	1.464E+04	1.037E+05	7.09	48.70
11	2.30	4.476E+03	1.435E+04	1.125E+05	7.84	48.72
12	2.75	4.699E+03	1.366E+04	1.180E+05	8.63	48.68
13	3.19	4.914E+03	1.345E+04	1.234E+05	9.19	48.69
14	3.63	5.100E+03	1.333E+04	1.279E+05	9.60	48.65

```
Least-Squares Line for Ho vs q curve:
   Slope      = -2.9438E-01
   Intercept  =  5.8472E+05

Least-squares line for q = a*delta-T^b
   a =  2.4011E+04
   b =  7.5000E-01


NOTE: 14 data points were stored in file FONMVNT4

NOTE: 14 X-Y pairs were stored in data file
```

```
NOTE: Program name : DRPOK
      Data taken by              : O'KEEFE
      This analysis done on file : FONMVNT5
      This analysis includes end-fin effect
      Thermal conductivity     = 21.0 (W/m.K)
      Inside diameter, Di      = 13.86 (mm)
      Outside diameter, Do     = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement   : SMOOTH TUBE
      Tube material      : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho
```

C1 (based on Petukhov-Popov)   = 1.1127
Alpha (based on Nusselt (Tdel)) = 0.9274
Enhancement (q)   =   .836
Enhancement (Del-T)   =   .913

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C)
1	3.64	5.029E+03	1.251E+04	1.289E+05	10.30	48.70
2	3.19	4.895E+03	1.291E+04	1.255E+05	9.72	48.73
3	2.75	4.735E+03	1.346E+04	1.209E+05	8.98	48.68
4	2.31	4.454E+03	1.353E+04	1.143E+05	8.45	48.73
5	1.86	4.116E+03	1.371E+04	1.054E+05	7.69	48.67
6	1.42	3.746E+03	1.490E+04	9.534E+04	6.40	48.66
7	0.97	3.180E+03	1.629E+04	7.999E+04	4.91	48.64
8	1.42	3.742E+03	1.490E+04	9.590E+04	6.44	48.70
9	0.97	3.180E+03	1.631E+04	8.016E+04	4.92	48.64
10	1.86	4.146E+03	1.408E+04	1.071E+05	7.60	48.71
11	2.31	4.489E+03	1.389E+04	1.159E+05	8.34	48.65
12	2.75	4.705E+03	1.327E+04	1.220E+05	9.19	48.72
13	3.19	4.894E+03	1.293E+04	1.266E+05	9.79	48.66
14	3.64	5.053E+03	1.269E+04	1.307E+05	10.30	48.64
15	2.31	4.487E+03	1.386E+04	1.151E+05	8.31	48.62
16	0.97	3.194E+03	1.662E+04	8.039E+04	4.94	48.76
17	3.64	5.053E+03	1.274E+04	1.312E+05	10.30	48.63

Least-Squares Line for Ho vs q curve:
  Slope   = -3.0266E-01
  Intercept = 5.8489E+05

Least-squares line for q = a*delta-T^b
  a = 2.3349E+04
  b = 7.5000E-01

NOTE: 17 data points were stored in file FONMVNT5

NOTE: 17 (-) pairs were stored in data file

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NOTE: Program name : ORPOK
      Data taken by   : O'KEEFE
      This analysis done on file : FONMAH1T1
      This analysis includes end-fin effect
      Thermal conductivity   = 21.0 (W/m.K)
      Inside diameter, D_1 = 13.86 (mm)
      Outside diameter, Do   = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
      Tube material   : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

C_1 (based on Petukhov-Popov)   = 2.0225
Alpha (based on Nusselt (Tdel)) = 0.7981
Enhancement (q)   = 1.047
Enhancement (Del-T)   = 1.035

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C
1	3.62	5.446E+03	1.036E+04	3.995E+05	38.45	99.98
2	3.18	5.361E+03	1.049E+04	3.896E+05	37.14	99.95
3	2.73	5.268E+03	1.071E+04	3.914E+05	35.61	100.01
4	2.29	5.071E+03	1.069E+04	3.654E+05	34.19	99.93
5	1.85	4.858E+03	1.087E+04	3.496E+05	32.17	100.01
6	1.41	4.568E+03	1.119E+04	3.269E+05	29.22	99.89
7	0.97	4.150E+03	1.200E+04	2.957E+05	24.63	99.94
8	1.41	4.565E+03	1.119E+04	3.273E+05	29.23	99.95
9	0.97	4.147E+03	1.197E+04	2.955E+05	24.68	99.99
10	1.85	4.863E+03	1.090E+04	3.513E+05	32.21	100.05
11	2.29	5.073E+03	1.070E+04	3.670E+05	34.29	100.05
12	2.73	5.252E+03	1.069E+04	3.905E+05	35.60	99.97
13	3.17	5.373E+03	1.052E+04	3.899E+05	36.96	99.99
14	3.61	5.467E+03	1.041E+04	3.953E+05	38.00	100.02

Least-Squares Line for Ho vs q curve:
   Slope   = -2.8216E-01
   Intercept = 7.7250E+05

Least-squares line for q = a*delta-T^b
   a = 2.5057E+04
   b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAH1T1

NOTE: 14 X-Y pairs were stored in data file

```
NOTE: Program name : DRPOK
      Data taken by                 : O'KEEFE
      This analysis done on file : FONMAN1T1
      This analysis includes end-fin effect
      Thermal conductivity        =  21.0 (W/m.K)
      Inside diameter, Di         = 13.86 (mm)
      Outside diameter, Do        = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement    : WIRE-WRAPPED SMOOTH TUBE
      Tube material       : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho
```

Ci (based on Petukhov-Popov)   =   1.1307
Alpha (based on Nusselt (Tdel))   =   0.7825
Enhancement (q)   =   1.030
Enhancement (Del-T)   =   1.022

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C)
1	3.61	4.807E+03	1.077E+04	3.467E+05	32.19	99.91
2	3.17	4.688E+03	1.104E+04	3.395E+05	30.76	99.99
3	2.73	4.497E+03	1.111E+04	3.257E+05	29.32	99.97
4	2.29	4.284E+03	1.133E+04	3.101E+05	27.36	99.93
5	1.85	3.979E+03	1.140E+04	2.883E+05	25.30	99.95
6	1.41	3.606E+03	1.170E+04	2.607E+05	22.28	99.95
7	0.97	3.138E+03	1.305E+04	2.259E+05	17.31	99.93
8	1.41	3.597E+03	1.165E+04	2.614E+05	22.43	99.99
9	0.97	3.150E+03	1.329E+04	2.272E+05	17.09	99.94
10	1.85	3.970E+03	1.141E+04	2.903E+05	25.44	99.93
11	2.29	4.251E+03	1.126E+04	3.122E+05	27.73	100.01
12	2.74	4.491E+03	1.115E+04	3.296E+05	29.55	99.99
13	3.18	4.650E+03	1.090E+04	3.412E+05	31.31	99.99
14	3.62	4.789E+03	1.075E+04	3.516E+05	32.71	100.05

Least-Squares Line for Ho vs q curve:
  Slope   = -2.4626E-01
  Intercept = 7.5014E+05

Least-squares line for q = a+delta-T b
  a = 2.5879E+04
  b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAN1T1

NOTE: 14 x-y pairs were stored in data file

```
NOTE: Program name : DRPOK
      Data taken by              : O'KEEFE
      This analysis done on file : FONMVH1T1
      This analysis includes end-fin effect
      Thermal conductivity      = 21.0 (W/m.K)
      Inside diameter, Di       = 13.86 (mm)
      Outside diameter, Do      = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement    : WIRE-WRAPPED SMOOTH TUBE
      Tube material       : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho
```

C₁ (based on Petukhov-Popov)   =   1.8918
Alpha (based on Nusselt (Tdel)) =   0.8018
Enhancement (q)   =   1.061
Enhancement (Del-T)   =   1.045

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.63	5.745E+03	1.196E+04	1.383E+05	11.56	48.65
2	3.19	5.661E+03	1.225E+04	1.364E+05	11.14	48.72
3	2.74	5.516E+03	1.244E+04	1.321E+05	10.62	48.65
4	2.30	5.291E+03	1.248E+04	1.269E+05	10.18	48.74
5	1.86	5.007E+03	1.256E+04	1.192E+05	9.49	48.65
6	1.41	4.660E+03	1.297E+04	1.105E+05	8.52	48.72
7	0.97	4.147E+03	1.379E+04	9.748E+04	7.07	48.58
8	1.41	4.655E+03	1.295E+04	1.107E+05	8.55	48.65
9	0.97	4.161E+03	1.396E+04	9.767E+04	6.99	48.59
10	1.86	5.005E+03	1.257E+04	1.203E+05	9.58	48.69
11	2.30	5.254E+03	1.228E+04	1.266E+05	10.31	48.73
12	2.74	5.500E+03	1.236E+04	1.321E+05	10.68	48.71
13	3.19	5.641E+03	1.215E+04	1.352E+05	11.13	48.69
14	3.63	5.740E+03	1.192E+04	1.365E+05	11.45	48.66

Least-Squares Line for Ho vs q curve:
   Slope   = -3.0415E-01
   Intercept = 5.8381E+05

Least-squares line for q = a*delta-T^b
   a = 2.2233E+04
   b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVH1T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : ORPOK
       Data taken by   : O'KEEFE
       This analysis done on file : FONMVN1T1
       This analysis includes end-fin effect
       Thermal conductivity   = 21.0 (W/m.K)
       Inside diameter, D_i = 13.86 (mm)
       Outside diameter, D_o = 15.85 (mm)
       This analysis uses the QUARTZ THERMOMETER readings
       Modified Petukhov-Popov coefficient   = 1.0000
       Using no insert inside tube
       Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
       Tube material   : TITANIUM
       Pressure condition : VACUUM
       Nusselt theory is used for Ho

C_1 (based on Petukhov-Popov)   =   1.0235
Alpha (based on Nusselt (Tdel)) =   0.8381
Enhancement (q)   =   1.029
Enhancement (Del-T)   =   1.021

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.63	5.036E+03	1.333E+04	1.191E+05	8.93	48.64
2	3.18	4.903E+03	1.395E+04	1.147E+05	8.29	48.70
3	2.74	4.718E+03	1.437E+04	1.093E+05	7.61	48.74
4	2.30	4.410E+03	1.427E+04	1.012E+05	7.09	48.71
5	1.85	4.088E+03	1.479E+04	9.300E+04	6.29	48.71
6	1.41	3.683E+03	1.550E+04	8.244E+04	5.32	48.68
7	0.97	3.071E+03	1.645E+04	6.840E+04	4.16	48.68
8	1.41	3.655E+03	1.542E+04	8.279E+04	5.37	48.68
9	0.97	3.074E+03	1.652E+04	6.840E+04	4.14	48.65
10	1.85	4.083E+03	1.475E+04	9.302E+04	6.31	48.63
11	2.30	4.405E+03	1.422E+04	1.012E+05	7.11	48.67
12	2.74	4.729E+03	1.444E+04	1.084E+05	7.50	48.65
13	3.18	4.906E+03	1.381E+04	1.125E+05	8.14	48.70
14	3.62	5.058E+03	1.340E+04	1.160E+05	8.66	48.72

Least-Squares Line for Ho vs q curve:
   Slope   = -2.5701E-01
   Intercept = 5.3022E+05

Least-squares line for $q = a \cdot delta\text{-}T^b$
   a = 2.3429E+04
   b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVN1T1

NOTE: 14 X-Y pairs were stored in data file

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NOTE: Program name : DRPOK
      Data taken by   : O'KEEFE
      This analysis done on file : FONMAH2T3
      This analysis includes end-fin effect
      Thermal conductivity   = 21.0 (W/m.K)
      Inside diameter, Di   = 13.96 (mm)
      Outside diameter, Do   = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
      Tube material   : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

C_i (based on Petukhov-Popov)   = 2.4479
Alpha (based on Nusselt (Tdel)) = 0.8064
Enhancement (q)   = 1.062
Enhancement (Del-T)   = 1.046

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.60	5.719E+03	1.054E+04	3.982E+05	37.78	99.95
2	3.16	5.593E+03	1.047E+04	3.876E+05	37.02	99.99
3	2.72	5.523E+03	1.072E+04	3.857E+05	35.99	100.00
4	2.28	5.382E+03	1.086E+04	3.767E+05	34.70	100.03
5	1.85	5.151E+03	1.087E+04	3.612E+05	33.23	100.01
6	1.41	4.895E+03	1.121E+04	3.426E+05	30.58	100.20
7	0.97	4.499E+03	1.186E+04	3.130E+05	26.39	99.99
8	1.41	4.867E+03	1.109E+04	3.429E+05	30.31	100.01
9	0.97	4.492E+03	1.183E+04	3.132E+05	26.48	99.95
10	1.85	5.139E+03	1.086E+04	3.649E+05	33.60	100.02
11	2.29	5.362E-03	1.083E+04	3.821E+05	35.29	99.97
12	2.73	5.487E+03	1.064E+04	3.919E+05	36.84	100.20
13	3.17	5.582E-03	1.049E+04	3.990E+05	38.02	99.99
14	3.61	5.706E+03	1.054E+04	4.079E+05	38.57	99.95

Least-Squares Line for Ho vs q curve:
   Slope   = -2.9602E-01
   Intercept = 7.7502E+05

Least-squares line for q = a*delta-T^b
   a = 2.5293E+04
   b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAH2T3

NOTE: 14 x-Y pairs were stored in data file

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NOTE: Program name : DRPOK
      Data taken by   : O'KEEFE
      This analysis done on file : FONMAN2T1
      This analysis includes end-fin effect
      Thermal conductivity   = 21.0 (W/m.K)
      Inside diameter, Di   = 13.86 (mm)
      Outside diameter, Do   = 15.95 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
      Tube material   : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

C_i (based on Petukhov-Popov)   =   1.0949
Alpha (based on Nusselt (Tdel)) =   0.8014
Enhancement (q)   =   1.063
Enhancement (Del-T)   =   1.047

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C)
1	0.97	3.104E+03	1.352E+04	2.237E+05	16.55	100.04
2	1.41	3.591E+03	1.217E+04	2.597E+05	21.33	99.99
3	1.85	3.987E+03	1.191E+04	2.876E+05	24.14	99.99
4	2.29	4.290E+03	1.175E+04	3.092E+05	26.32	99.95
5	2.73	4.512E+03	1.149E+04	3.242E+05	28.21	99.94
6	3.17	4.716E+03	1.145E+04	3.387E+05	29.60	100.01
7	3.61	4.953E+03	1.122E+04	3.475E+05	30.97	99.99
8	3.17	4.734E+03	1.151E+04	3.376E+05	29.32	99.97
9	3.61	4.873E+03	1.131E+04	3.477E+05	30.73	99.94
10	2.73	4.531E+03	1.154E+04	3.218E+05	27.89	99.93
11	2.29	4.298E+03	1.168E+04	3.047E+05	26.09	99.94
12	1.85	3.968E+03	1.159E+04	2.813E+05	24.29	99.95
13	1.41	3.602E+03	1.201E+04	2.543E+05	21.13	99.95
14	0.97	3.164E+03	1.413E+04	2.225E+05	15.75	100.07

Least-Squares Line for Ho vs q curve:
  Slope   = -2.3609E-01
  Intercept = 7.5845E-05

Least-squares line for q = a*delta-T^b
  a = 2.6571E+04
  b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAN2T1

NOTE: 14 X-Y pairs were stored in data file

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```
NOTE: Program name : DRPCK
      Data taken by              : O'KEEFE
      This analysis done on file : FONMVH2T1
      This analysis includes end-fin effect
      Thermal conductivity     = 21.0 (W/m.K)
      Inside diameter, Di      = 13.86 (mm)
      Outside diameter, Do     = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
      Tube material      : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho
```

C_1 (based on Petukhov-Popov)   = 2.0049
Alpha (based on Nusselt (Tdel)) = 0.7965
Enhancement (q)   = 1.052
Enhancement (Del-T)   = 1.038

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C
1	3.64	5.753E+03	1.174E+04	1.466E+05	12.49	48.73
2	3.19	5.631E+03	1.181E+04	1.423E+05	12.04	48.69
3	2.75	5.462E+03	1.182E+04	1.363E+05	11.53	48.63
4	2.52	5.369E+03	1.186E+04	1.341E+05	11.31	48.80
5	2.30	5.263E+03	1.190E+04	1.315E+05	11.05	48.35
6	1.86	4.949E+03	1.172E+04	1.225E+05	10.46	48.70
7	1.42	4.621E+03	1.203E+04	1.132E+05	9.41	48.63
8	0.97	4.146E+03	1.277E+04	1.014E+05	7.94	48.30
9	0.97	4.229E+03	1.364E+04	1.035E+05	7.58	48.54
10	1.42	4.657E+03	1.230E+04	1.153E+05	9.37	48.65
11	1.86	5.011E+03	1.209E+04	1.247E+05	10.32	48.65
12	2.30	5.284E+03	1.203E+04	1.321E+05	10.98	48.66
13	2.53	5.348E+03	1.177E+04	1.341E+05	11.39	48.74

Least-Squares Line for Ho vs q curve:
   Slope   = -2.9344E-01
   Intercept = 5.8163E+05

Least-squares line for q = a*delta-T^b
   a = 2.1707E+04
   b = 7.5000E-01

NOTE: 13 data points were stored in file FONMVH2T1

NOTE: 13 X-Y pairs were stored in data file

```
NOTE: Program name : DRPOK
      Data taken by                : O'KEEFE
      This analysis done on file : FONMVH2T2
      This analysis includes end-fin effect
      Thermal conductivity       = 21.0 (W/m.K)
      Inside diameter, Di        = 13.86 (mm)
      Outside diameter, Do       = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
      Tube material      : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho
```

C_1 (based on Petukhov-Popov)   =   1.9482
Alpha (based on Nusselt (Tdel)) =   0.7873
Enhancement (q)   =   1.035
Enhancement (Del-T)   =   1.026

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.64	5.614E+03	1.134E+04	1.454E+05	12.92	48.64
2	3.19	5.552E+03	1.166E+04	1.425E+05	12.23	48.64
3	2.75	5.383E+03	1.168E+04	1.380E+05	11.82	48.75
4	2.53	5.288E+03	1.171E+04	1.348E+05	11.51	48.67
5	2.31	5.193E+03	1.181E+04	1.326E+05	11.22	48.77
6	1.86	4.952E+03	1.205E+04	1.263E+05	10.48	48.91
7	1.42	4.573E+03	1.213E+04	1.155E+05	9.52	48.68
8	0.97	4.107E+03	1.303E+04	1.024E+05	7.86	48.71
9	1.42	4.582E+03	1.219E+04	1.156E+05	9.49	48.70
10	0.97	4.121E+03	1.316E+04	1.025E+05	7.79	48.69
11	2.31	5.164E+03	1.167E+04	1.316E+05	11.29	48.66
12	3.64	5.630E+03	1.139E+04	1.443E+05	12.67	48.65
13	3.19	5.480E+03	1.134E+04	1.398E+05	12.33	48.58

Least-Squares Line for Ho vs q curve:
  Slope   = -3.2945E-01
  Intercept = 5.8591E+05

Least-squares line for q = a*delta-T^b
  a = 2.1568E+04
  b = 7.5000E-01

NOTE: 13 data points were stored in file FONMVH2T2

NOTE: 13 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
      Data taken by   : O'KEEFE
      This analysis done on file : FONMVH2T3
      This analysis includes end-fin effect
      Thermal conductivity   = 21.0 (W/m.K)
      Inside diameter, D_1 = 13.86 (mm)
      Outside diameter, Do   = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
      Tube material   : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho

C_1 (based on Petukhov-Popov)   = 2.2400
Alpha (based on Nusselt (Tdel)) = 0.7662
Enhancement (q)   =   .999
Enhancement (Del-T)   =   .999

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.63	5.823E+03	1.143E+04	1.395E+05	12.20	48.63
2	3.18	5.684E+03	1.138E+04	1.353E+05	11.89	48.64
3	2.74	5.568E+03	1.155E+04	1.320E+05	11.43	48.63
4	2.30	5.354E+03	1.149E+04	1.267E+05	11.02	48.64
5	1.86	5.135E+03	1.170E+04	1.209E+05	10.33	48.65
6	1.41	4.825E+03	1.201E+04	1.132E+05	9.43	48.70
7	0.97	4.405E+03	1.300E+04	1.015E+05	7.81	48.71
8	1.41	4.927E+03	1.203E+04	1.138E+05	9.46	48.67
9	0.97	4.383E+03	1.292E+04	1.015E+05	7.92	48.72
10	1.86	5.126E+03	1.167E+04	1.223E+05	10.48	48.74
11	2.30	5.341E+03	1.145E+04	1.275E+05	11.14	48.62
12	2.74	5.553E+03	1.150E+04	1.334E+05	11.60	48.70
13	3.19	5.669E+03	1.133E+04	1.353E+05	11.99	48.61
14	3.63	5.802E+03	1.135E+04	1.400E+05	12.33	48.74

Least-Squares Line for Ho vs q curve:
   Slope   = -3.3576E-01
   Intercept = 5.8581E+05

Least-squares line for q = a+delta-T^b
   a = 2.1177E+04
   b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVH2T3

NOTE: 14 X-Y pairs were stored in data file

134

```
NOTE: Program name : DRPOK
      Data taken by               : O'KEEFE
      This analysis done on file : FONMVN2T1
      This analysis includes end-fin effect
      Thermal conductivity     = 21.0 (W/m.K)
      Inside diameter, Di       = 13.86 (mm)
      Outside diameter, Do      = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement  : WIRE-WRAPPED SMOOTH TUBE
      Tube material     : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho
```

Ci (based on Petukhov-Popov)   = 0.9979
Alpha (based on Nusselt (Tdel)) = 0.3181
Enhancement (q)   =   .996
Enhancement (Del-T)   =   .997

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	0.97	2.991E+03	1.622E+04	7.061E+04	4.35	48.71
2	1.41	3.543E+03	1.476E+04	8.456E+04	5.73	48.66
3	1.86	3.947E+03	1.394E+04	9.451E+04	6.79	48.66
4	2.30	4.306E+03	1.392E+04	1.032E+05	7.42	48.65
5	2.74	4.548E+03	1.342E+04	1.088E+05	8.10	48.67
6	2.74	4.582E+03	1.372E+04	1.092E+05	7.96	48.63
7	3.18	4.765E+03	1.322E+04	1.138E+05	8.61	48.69
8	3.63	5.009E+03	1.350E+04	1.194E+05	8.85	48.68
9	3.18	4.784E+03	1.334E+04	1.135E+05	8.51	49.66
10	3.63	4.978E+03	1.325E+04	1.182E+05	8.92	48.70
11	2.74	4.556E+03	1.345E+04	1.078E+05	8.02	48.72
12	2.30	4.311E+03	1.389E+04	1.016E+05	7.31	48.68
13	1.86	3.971E+03	1.413E+04	9.320E+04	6.59	49.70
14	1.41	3.548E+03	1.465E+04	8.254E+04	5.63	48.66
15	0.97	2.987E+03	1.585E+04	6.885E+04	4.34	48.71

Least-Squares Line for Ho vs q curve:
  Slope   = -2.6538E-01
  Intercept = 5.8038E+05

Least-squares line for q = a*delta-T^b
  a = 2.2839E+04
  b = 7.5000E-01

NOTE: 15 data points were stored in file FONMVN2T1

NOTE: 15 X-Y pairs were stored in data file

135

NOTE: Program name : DRPOK
      Data taken by   : O'KEEFE
      This analysis done on file : FONMVN3T1
      This analysis includes end-fin effect
      Thermal conductivity   = 21.0 (W/m.K)
      Inside diameter, D_1 = 13.86 (mm)
      Outside diameter, D_o = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
      Tube material   : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho

C_1 (based on Petukhov-Popov)   = 0.9111
Alpha (based on Nusselt (Tdel)) = 0.6359
Enhancement (q)   =   .624
Enhancement (Del-T)   =   .702

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C
1	3.64	4.261E+03	9.903E+03	1.078E+05	10.89	48.61
2	3.19	4.046E+03	9.629E+03	1.034E+05	10.73	48.86
3	2.75	3.864E+03	9.694E+03	9.833E+04	10.14	48.76
4	2.30	3.695E+03	1.016E+04	9.272E+04	9.13	48.43
5	1.86	3.435E+03	1.049E+04	8.615E+04	8.22	48.48
6	0.97	2.619E+03	1.170E+04	6.453E+04	5.52	48.49
7	1.42	3.070E+03	1.067E+04	7.722E+04	7.24	48.63
8	0.97	2.649E+03	1.238E+04	6.524E+04	5.27	48.32
9	1.42	3.072E+03	1.072E+04	7.736E+04	7.22	48.54
10	1.86	3.352E+03	9.765E+03	8.670E+04	8.38	49.08
11	2.31	3.716E+03	1.034E+04	9.406E+04	9.10	48.44
12	2.75	3.859E+03	9.681E+03	9.967E+04	10.30	48.92
13	3.19	4.091E+03	9.905E+03	1.040E+05	10.50	48.50
14	3.54	4.275E+03	9.995E+03	1.085E+05	10.66	48.43

Least-Squares Line for Ho vs q curve:
   Slope   = -3.4927E-01
   Intercept = 5.8044E+05

Least-squares line for q = a*delta-T^b
   a = 1.7709E+04
   b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVN3T1

NOTE: 14 X-Y pairs were stored in data file

136

```
NOTE: Program name : DRPOK
      Data taken by              : O'KEEFE
      This analysis done on file : FONMAH3T1
      This analysis includes end-fin effect
      Thermal conductivity      =  21.0 (W/m.K)
      Inside diameter, Di       =  13.86 (mm)
      Outside diameter, Do      =  15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
      Tube material      : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho
```

Ci (based on Petukhov-Popov)   =   2.1377
Alpha (based on Nusselt (Tdel)) =   0.7239
Enhancement (q)   =   .872
Enhancement (Del-T)   =   .902

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.62	5.173E+03	9.249E+03	3.780E+05	40.88	99.86
2	3.18	5.068E+03	9.251E+03	3.717E+05	40.18	100.01
3	2.74	4.950E+03	9.289E+03	3.634E+05	39.12	100.09
4	2.30	4.830E+03	9.456E+03	3.538E+05	37.41	99.96
5	1.85	4.616E+03	9.475E+03	3.377E+05	35.64	99.91
6	1.41	4.409E+03	9.947E+03	3.229E+05	32.46	100.11
7	0.97	4.014E+03	1.042E+04	2.923E+05	28.05	100.13
8	1.41	4.374E+03	9.784E+03	3.200E+05	32.70	99.81
9	0.97	4.028E+03	1.051E+04	2.924E+05	27.81	99.90
10	1.85	4.619E+03	9.508E+03	3.400E+05	35.76	99.92
11	2.30	4.790E+03	9.326E+03	3.533E+05	37.95	99.88
12	2.74	4.971E+03	9.385E+03	3.665E+05	39.05	99.75
13	3.18	5.054E+03	9.224E+03	3.749E+05	40.65	100.17
14	3.62	5.149E+03	9.139E+03	3.821E+05	41.58	100.15

Least-Squares Line for Ho vs q curve:
  Slope   = -3.3392E-01
  Intercept = 7.7974E+05

Least-squares line for q = a*delta-T b
  a = 2.3441E+04
  b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAH3T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
      Data taken by   : O'KEEFE
      This analysis done on file : FONMAN3T1
      This analysis includes end-fin effect
      Thermal conductivity   = 21.0 (W/m.K)
      Inside diameter, D_i = 13.86 (mm)
      Outside diameter, D_o = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petuknov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
      Tube material   : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

C_i (based on Petukhov-Popov)   = 1.0337
Alpha (based on Nusselt (Tdel)) = 0.6976
Enhancement (q)   =   .854
Enhancement (Del-T)   =   .838

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C)
1	3.63	4.380E+03	9.469E+03	3.271E+05	34.55	99.99
2	3.19	4.296E+03	9.764E+03	3.183E+05	32.60	99.60
3	2.74	4.068E+03	9.592E+03	3.044E+05	31.73	100.24
4	2.30	3.881E+03	9.813E+03	2.889E+05	29.44	99.97
5	1.86	3.576E+03	9.664E+03	2.665E+05	27.57	100.05
6	1.41	3.275E+03	1.023E+04	2.435E+05	23.79	99.97
7	0.97	2.867E+03	1.169E+04	2.120E+05	18.13	99.93
8	1.41	3.275E+03	1.025E+04	2.441E+05	23.81	99.99
9	0.97	2.863E+03	1.167E+04	2.123E+05	18.20	100.00
10	1.86	3.590E+03	9.795E+03	2.683E+05	27.40	100.01
11	2.30	3.860E+03	9.709E+03	2.889E+05	29.75	100.06
12	2.74	4.087E+03	9.713E+03	3.053E+05	31.49	100.00
13	3.19	4.250E+03	9.590E+03	3.179E+05	33.14	99.95
14	3.63	4.399E+03	9.560E+03	3.290E+05	34.42	99.97

Least-Squares Line for Ho vs q curve:
  Slope   = -2.8762E-01
  Intercept = 7.6233E+05

Least-squares line for q = a*delta-T b
  a = 2.2978E+04
  b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAN3T1

NOTE: 14 X-Y pairs were stored in data file

138

NOTE: Program name : DRPOK
      Data taken by   : O'KEEFE
      This analysis done on file : FONMVH3T2
      This analysis includes end-fin effect
      Thermal conductivity   = 21.0 (W/m.K)
      Inside diameter, D_i = 13.86 (mm)
      Outside diameter, Do   = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
      Tube material   : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho

C_i (based on Petukhov-Popov)   = 1.8658
Alpha (based on Nusselt (Tdel)) = 0.6182
Enhancement (q)   =   .638
Enhancement (Del-T)   =   .714

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C)
1	0.97	3.760E+03	1.046E+04	8.859E+04	8.47	48.70
2	1.41	4.094E+03	9.489E+03	9.805E+04	10.33	48.72
3	1.86	4.370E+03	9.286E+03	1.049E+05	11.30	48.67
4	2.30	4.582E+03	9.216E+03	1.114E+05	12.09	48.83
5	2.74	4.733E+03	9.123E+03	1.144E+05	12.54	48.70
6	3.19	4.798E+03	8.870E+03	1.165E+05	13.14	48.78
7	3.63	4.986E+03	9.127E+03	1.207E+05	13.23	48.71
8	3.19	4.835E+03	8.993E+03	1.174E+05	13.06	48.88
9	3.63	4.991E+03	9.142E+03	1.208E+05	13.19	48.70
10	2.74	4.753E+03	9.191E+03	1.142E+05	12.43	48.74
11	2.30	4.573E+03	9.156E+03	1.093E+05	11.92	48.72
12	1.86	4.391E+03	9.369E+03	1.040E+05	11.10	48.65
13	1.41	4.130E+03	9.662E+03	9.732E+04	10.07	48.63
14	0.97	3.751E+03	1.036E+04	8.735E+04	8.43	48.72

Least-Squares Line for Ho vs q curve:
   Slope   = -4.1572E-01
   Intercept = 5.8640E+05

Least-squares line for q = a*delta-T^b
   a = 1.7233E+04
   b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVH3T2

NOTE: 14 X-Y pairs were stored in data file

139

NOTE: Program name : DRPOK
      Data taken by   : O'KEEFE
      This analysis done on file : FONMAH4T1
      This analysis includes end-fin effect
      Thermal conductivity   = 21.0 (W/m.K)
      Inside diameter, Di   = 13.86 (mm)
      Outside diameter, Do   = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
      Tube material   : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

C_i (based on Petukhov-Popov)   = 2.3785
Alpha (based on Nusselt (Tdel)) = 0.8529
Enhancement (q)   = 1.144
Enhancement (Del-T)   = 1.106

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.62	5.824E+03	1.114E+04	4.309E+05	38.63	99.98
2	3.18	5.742E+03	1.128E+04	4.235E+05	37.56	100.02
3	2.74	5.616E+03	1.136E+04	4.128E+05	36.34	99.96
4	2.30	5.449E+03	1.145E+04	3.989E+05	34.94	99.89
5	1.85	5.213E+03	1.152E+04	3.825E+05	33.19	100.07
6	1.41	4.921E+03	1.161E+04	3.593E+05	30.41	100.04
7	0.97	4.520E+03	1.273E+04	3.276E+05	25.72	99.95
8	1.41	4.901E+03	1.171E+04	3.586E+05	30.52	100.03
9	0.97	4.519E+03	1.272E+04	3.274E+05	25.74	99.97
10	1.85	5.229E+03	1.160E+04	3.838E+05	33.10	99.96
11	2.30	5.444E+03	1.144E+04	4.006E+05	35.01	100.00
12	2.74	5.614E+03	1.136E+04	4.135E+05	36.40	99.95
13	3.19	5.713E+03	1.116E+04	4.209E+05	37.71	99.98
14	3.62	5.910E+03	1.108E+04	4.290E+05	38.64	99.99

Least-Squares Line for Ho vs q curve:
   Slope   = -2.6757E-01
   Intercept = 7.7418E+05

Least-squares line for $q = a*delta-T^b$
   a = 2.7891E+04
   b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAH4T1

NOTE: 14 X-Y pairs were stored in data file

```
NOTE: Program name  : DRPOK
      Data taken by            : O'KEEFE
      This analysis done on file : FONMAN4T1
      This analysis includes end-fin effect
      Thermal conductivity      =  21.0 (W/m.K)
      Inside diameter, Di       = 13.86 (mm)
      Outside diameter, Do      = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient  = 1.0000
      Using no insert inside tube
      Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
      Tube material      : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho
```

Ci (based on Petukhov-Popov)   =   1.3768
Alpha (based on Nusselt (Tdel)) =   0.7912
Enhancement (q)   =   1.045
Enhancement (Del-T)   =   1.034

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.63	5.090E+03	1.092E+04	3.804E+05	34.85	99.98
2	3.18	4.936E+03	1.089E+04	3.658E+05	33.58	99.94
3	2.74	4.757E+03	1.092E+04	3.519E+05	32.20	99.99
4	2.30	4.522E+03	1.089E+04	3.336E+05	30.52	99.97
5	1.85	4.214E+03	1.078E+04	3.103E+05	29.79	99.95
6	1.41	3.872E+03	1.109E+04	2.848E+05	25.58	99.95
7	0.97	3.497E+03	1.310E+04	2.553E+05	19.52	100.00
8	1.41	3.364E+03	1.104E+04	2.848E+05	25.30	99.97
9	0.97	3.519E+03	1.343E+04	2.573E+05	19.15	99.91
10	1.86	4.211E+03	1.079E+04	3.114E+05	28.86	99.94
11	2.30	4.527E+03	1.094E+04	3.348E+05	30.61	99.95
12	2.74	4.751E+03	1.090E+04	3.513E+05	32.24	99.92
13	3.18	4.945E+03	1.093E+04	3.662E+05	33.50	99.97
14	3.62	5.101E+03	1.093E+04	3.776E+05	34.56	99.97

Least-Squares Line for Ho vs q curve:
  Slope   = -2.4793E-01
  Intercept = 7.6032E-05

Least-squares line for q = a+delta-T^b
  a = 2.5008E-04
  b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAN4T1

NOTE: 14 X-Y pairs were stored in data file

```
NOTE: Program name : DRPOK
      Data taken by               : O'KEEFE
      This analysis done on file : FONMVH4T1
      This analysis includes end-fin effect
      Thermal conductivity      =  21.0 (W/m.K)
      Inside diameter, Di       = 13.86 (mm)
      Outside diameter, Do      = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement    : WIRE-WRAPPED SMOOTH TUBE
      Tube material       : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho
```

C₁ (based on Petukhov-Popov)   = 2.0810
Alpha (based on Nusselt (Tdel)) = 0.8211
Enhancement (q)   = 1.095
Enhancement (Del-T)   = 1.071

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.63	5.967E+03	1.241E+04	1.468E+05	11.83	48.70
2	3.19	5.798E+03	1.229E+04	1.417E+05	11.52	48.70
3	2.74	5.668E+03	1.251E+04	1.380E+05	11.03	48.74
4	2.30	5.424E+03	1.239E+04	1.313E+05	10.59	48.70
5	1.86	5.192E+03	1.272E+04	1.252E+05	9.85	48.73
6	1.41	4.872E+03	1.326E+04	1.168E+05	8.81	48.74
7	0.97	4.393E+03	1.440E+04	1.038E+05	7.21	48.67
8	1.41	4.884E+03	1.337E+04	1.175E+05	8.79	48.67
9	0.97	4.402E+03	1.451E+04	1.044E+05	7.20	48.70
10	1.86	5.207E+03	1.282E+04	1.263E+05	9.85	48.72
11	2.30	5.449E+03	1.254E+04	1.327E+05	10.58	48.69
12	2.74	5.653E+03	1.244E+04	1.377E+05	11.07	48.69
13	3.19	5.793E+03	1.226E+04	1.407E+05	11.48	48.76
14	3.63	5.943E+03	1.229E+04	1.441E+05	11.73	48.70

Least-Squares Line for Ho vs q curve:
   Slope   = -3.1730E-01
   Intercept = 5.8664E+05

Least-squares line for q = a*delta-T^b
   a = 2.2845E+04
   b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVH4T1

NOTE: 14 X-Y pairs were stored in data file

```
NOTE: Program name : DRPOK
      Data taken by                : O'KEEFE
      This analysis done on file : FONMVN4T1
      This analysis includes end-fin effect
      Thermal conductivity      =   21.0 (W/m.K)
      Inside diameter, Di        = 13.86 (mm)
      Outside diameter, Do       = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
      Tube material      : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho
```

Ci (based on Petukhov-Popov)   =   1.1394
Alpha (based on Nusselt (Tdel)) =   0.8245
Enhancement (q)   =   1.007
Enhancement (Del-T)   =   1.005

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C)
1	3.64	5.167E+03	1.309E+04	1.307E+05	9.99	48.71
2	3.19	4.973E+03	1.310E+04	1.248E+05	9.53	48.66
3	2.75	4.780E+03	1.339E+04	1.196E+05	8.93	48.68
4	2.30	4.490E+03	1.333E+04	1.121E+05	8.41	48.67
5	1.86	4.130E+03	1.322E+04	1.029E+05	7.79	48.70
6	1.42	3.722E+03	1.369E+04	9.235E+04	6.75	48.66
7	0.97	3.186E+03	1.500E+04	7.819E+04	5.21	48.70
8	1.42	3.727E+03	1.377E+04	9.296E+04	6.75	48.74
9	0.97	3.205E+03	1.544E+04	7.870E+04	5.10	48.70
10	1.86	4.125E+03	1.319E+04	1.032E+05	7.93	48.67
11	2.30	4.483E+03	1.330E+04	1.127E+05	8.47	48.67
12	2.75	4.737E+03	1.308E+04	1.197E+05	9.15	48.72
13	3.19	4.955E+03	1.299E+04	1.257E+05	9.68	48.74
14	3.64	5.165E+03	1.309E+04	1.311E+05	10.02	48.69
15	2.30	4.473E+03	1.321E+04	1.127E+05	8.53	48.72
16	0.97	3.210E+03	1.559E+04	7.913E+04	5.07	48.70
17	3.64	5.150E+03	1.301E+04	1.315E+05	10.11	48.71

Least-Squares Line for Ho vs q curve:
  Slope   = -2.6143E-01
  Intercept = 5.7985E+05

Least-squares line for q = a*delta-T^b
  a = 2.2773E+04
  b = 7.5000E-01

NOTE: 17 data points were stored in file FONMVN4T1

NOTE. 17 X-Y pairs were stored in data file

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```
NOTE: Program name : DRPOK
      Data taken by               : O'KEEFE
      This analysis done on file : FONMAHST1
      This analysis includes end-fin effect
      Thermal conductivity       = 21.0 (W/m.K)
      Inside diameter, Di         = 13.86 (mm)
      Outside diameter, Do        = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement    : WIRE-WRAPPED SMOOTH TUBE
      Tube material       : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho
```

C_i (based on Petukhov-Popov)   =   2.2507
Alpha (based on Nusselt (Tdel)) =   0.8691
Enhancement (q)   =   1.173
Enhancement (Del-T)   =   1.127

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C
1	3.60	5.914E+03	1.155E+04	4.113E+05	35.61	99.96
2	3.16	5.820E+03	1.165E+04	4.011E+05	34.43	100.02
3	2.72	5.727E+03	1.189E+04	3.917E+05	32.93	100.03
4	2.28	5.544E+03	1.196E+04	3.769E+05	31.52	99.92
5	1.84	5.333E+03	1.220E+04	3.613E+05	29.62	100.03
6	1.40	5.012E+03	1.244E+04	3.367E+05	27.07	99.95
7	0.96	4.578E+03	1.333E+04	3.054E+05	22.91	99.99
8	1.40	5.013E+03	1.246E+04	3.375E+05	27.09	99.93
9	0.96	4.582E+03	1.335E+04	3.055E+05	22.99	100.02
10	1.84	5.323E+03	1.216E+04	3.607E+05	29.63	99.92
11	2.28	5.574E+03	1.209E+04	3.785E+05	31.30	99.97
12	2.72	5.745E+03	1.196E+04	3.907E+05	32.63	99.99
13	3.15	5.848E+03	1.173E+04	3.975E+05	33.88	99.96
14	3.59	5.979E+03	1.174E+04	4.064E+05	34.50	99.95
15	3.15	5.826E+03	1.154E+04	3.949E+05	33.93	99.99
16	3.59	5.992E+03	1.190E+04	4.066E+05	34.47	99.97

Least-Squares Line for Ho vs q curve:
   Slope   = -2.4930E-01
   Intercept   = 7.6900E+05

Least-squares line for q = a+delta-T^b
   a = 2.8492E+04
   b = 7.5000E-01

NOTE: 16 data points were stored in file FONMAHST1

NOTE: 16 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
      Data taken by   : O'KEEFE
      This analysis done on file : FONMANST1
      This analysis includes end-fin effect
      Thermal conductivity   = 21.0 (W/m.K)
      Inside diameter, Di   = 13.86 (mm)
      Outside diameter, Do   = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
      Tube material   : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)   =   1.0988
Alpha (based on Nusselt (Tdel)) =   0.9367
Enhancement (q)   =   1.126
Enhancement (Del-T)   =   1.093

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C)
1	3.16	4.852E+03	1.203E+04	3.362E+05	27.95	99.95
2	2.72	4.685E+03	1.233E+04	3.227E+05	26.16	99.92
3	2.28	4.429E+03	1.238E+04	3.042E+05	24.57	100.01
4	1.84	4.108E+03	1.244E+04	2.809E+05	22.58	99.95
5	1.40	3.720E+03	1.286E+04	2.539E+05	19.74	100.04
6	0.96	3.248E+03	1.494E+04	2.203E+05	14.74	99.91
7	1.40	3.709E+03	1.279E+04	2.538E+05	19.85	99.92
8	0.96	3.235E+03	1.471E+04	2.200E+05	14.85	99.96
9	1.84	4.106E+03	1.249E+04	2.825E+05	22.63	99.95
10	2.28	4.423E+03	1.237E+04	3.052E+05	24.67	100.02
11	2.72	4.682E+03	1.232E+04	3.235E+05	26.26	100.03
12	3.61	5.010E+03	1.198E+04	3.534E+05	29.50	100.00
13	3.17	4.845E+03	1.219E+04	3.473E+05	29.49	99.93
14	3.61	5.004E+03	1.204E+04	3.592E+05	29.84	100.02

Least-Squares Line for Ho vs q curve:
   Slope   = -2.1506E-01
   Intercept = 7.5527E+05

Least-squares line for q = a*delta-T^b
   a = 2.7811E+04
   b = 7.5000E-01

NOTE: 14 data points were stored in file FONMANST1

NOTE: 14 X-Y pairs were stored in data file

```
NOTE: Program name : DRPOK
      Data taken by                : O'KEEFE
      This analysis done on file : FONMVHST1
      This analysis includes end-fin effect
      Thermal conductivity     = 21.0 (W/m.K)
      Inside diameter, Di      = 13.86 (mm)
      Outside diameter, Do     = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
      Tube material      : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho
```

C_1 (based on Petukhov-Popov)   = 2.0139
Alpha (based on Nusselt (Tdel)) = 0.8415
Enhancement (q)   = 1.132
Enhancement (Del-T)   = 1.097

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C
1	3.63	6.026E+03	1.281E+04	1.423E+05	11.11	48.66
2	3.18	5.928E+03	1.304E+04	1.376E+05	10.55	48.70
3	2.74	5.738E+03	1.301E+04	1.308E+05	10.05	48.61
4	2.30	5.558E+03	1.329E+04	1.254E+05	9.43	48.61
5	1.85	5.293E+03	1.354E+04	1.196E+05	8.76	48.71
6	1.41	4.928E+03	1.394E+04	1.093E+05	7.84	48.73
7	0.97	4.410E+03	1.497E+04	9.625E+04	6.43	48.70
8	1.41	4.910E+03	1.381E+04	1.091E+05	7.90	48.63
9	0.97	4.407E+03	1.493E+04	9.616E+04	6.44	48.71
10	1.85	5.301E+03	1.360E+04	1.188E+05	8.74	48.55
11	2.30	5.540E+03	1.318E+04	1.248E+05	9.47	48.58
12	2.74	5.772E+03	1.316E+04	1.302E+05	9.89	48.66
13	3.18	5.911E+03	1.292E+04	1.336E+05	10.34	48.72
14	3.62	6.113E+03	1.314E+04	1.371E+05	10.43	48.65
15	2.29	5.558E+03	1.325E+04	1.235E+05	9.32	48.73
16	3.62	6.097E+03	1.306E+04	1.364E+05	10.44	48.69

```
Least-Squares Line for Ho vs q curve:
   Slope     = -2.3741E-01
   Intercept =  5.9357E-05

Least-squares line for q = a*delta-T^b
   a =  2.3376E+04
   b =  7.5000E-01


NOTE: 16 data points were stored in file FONMVHST1

NOTE: 16 X-Y pairs were stored in data file
```

```
NOTE: Program name : DRPOK
      Data taken by              : O'KEEFE
      This analysis done on file : FONMVN5T1
      This analysis includes end-fin effect
      Thermal conductivity    = 21.0 (W/m.K)
      Inside diameter, Di      = 13.86 (mm)
      Outside diameter, Do     = 15.85 (mm)              .
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement    : WIRE-WRAPPED SMOOTH TUBE
      Tube material       : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho


C1 (based on Petukhov-Popov)     =   0.9775
Alpha (based on Nusselt (Tdel)) =   0.8425
Enhancement (q)                  =   1.036
Enhancement (Del-T)              =   1.027
```

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.63	4.995E+03	1.364E+04	1.180E+05	8.65	48.71
2	3.18	4.834E+03	1.401E+04	1.122E+05	8.01	48.62
3	2.74	4.638E+03	1.449E+04	1.068E+05	7.37	48.63
4	2.30	4.365E+03	1.480E+04	9.953E+04	6.73	48.65
5	1.85	3.996E+03	1.484E+04	9.080E+04	6.12	48.72
6	1.41	3.561E+03	1.539E+04	7.982E+04	5.19	48.62
7	0.97	2.988E+03	1.665E+04	6.614E+04	3.97	48.63
8	1.41	3.545E+03	1.511E+04	7.963E+04	5.27	48.62
9	0.97	2.989E+03	1.670E+04	6.637E+04	3.98	48.67
10	1.85	4.001E+03	1.493E+04	9.108E+04	6.10	48.67
11	2.30	4.334E+03	1.446E+04	9.877E+04	6.83	48.63
12	2.74	4.628E+03	1.436E+04	1.059E+05	7.37	48.70
13	3.19	4.830E+03	1.392E+04	1.104E+05	7.93	48.65
14	3.62	5.056E+03	1.401E+04	1.156E+05	8.25	48.72
15	2.29	4.348E+03	1.455E+04	9.797E+04	6.73	48.65
16	0.97	3.024E+03	1.763E+04	6.515E+04	3.75	48.69

```
Least-Squares Line for Ho vs q curve:
  Slope      = -2.4722E-01
  Intercept  =  5.7933E+05


Least-squares line for q = a*delta-T^b
  a =  2.3546E+04
  b =  7.5000E-01



NOTE: 16 data points were stored in file FONMVN5T1

NOTE: 16 X-Y pairs were stored in data file
```

```
NOTE: Program name : DRPOK
      Data taken by              : O'KEEFE
      This analysis done on file : FONMAH6T2
      This analysis includes end-fin effect
      Thermal conductivity     =  21.0 (W/m.K)
      Inside diameter, Di      =  13.86 (mm)
      Outside diameter, Do     =  15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient  = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
      Tube material      : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho
```

Ci (based on Petukhov-Popov)   = 2.3893
Alpha (based on Nusselt (Tdel)) = 0.9933
Enhancement (q)   = 1.402
Enhancement (Del-T)   = 1.299

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	1.85	5.666E+03	1.385E+04	4.083E+05	29.48	99.95
2	1.41	5.331E+03	1.432E+04	3.841E+05	26.83	99.98
3	0.97	4.821E+03	1.517E+04	3.453E+05	22.76	100.08
4	1.41	5.328E+03	1.432E+04	3.844E+05	26.84	99.99
5	0.97	4.842E+03	1.540E+04	3.475E+05	22.56	100.09
6	1.85	5.679E+03	1.397E+04	4.132E+05	29.58	100.05
7	2.29	5.932E+03	1.374E+04	4.326E+05	31.47	99.99
8	2.74	6.114E+03	1.354E+04	4.465E+05	32.98	99.97
9	3.18	6.271E+03	1.345E+04	4.584E+05	34.08	99.95
10	3.62	6.379E+03	1.330E+04	4.668E+05	35.10	100.01
11	3.18	6.278E+03	1.347E+04	4.585E+05	34.03	100.06
12	3.62	6.392E+03	1.335E+04	4.674E+05	35.01	100.04
13	2.74	6.130E+03	1.360E+04	4.460E+05	32.80	100.00
14	2.29	5.932E+03	1.372E+04	4.309E+05	31.40	100.02

```
Least-Squares Line for Ho vs q curve:
   Slope     = -2.1639E-01
   Intercept =  7.6861E+05

Least-squares line for q = a*delta-T^b
   a =  3.2516E+04
   b =  7.5000E-01


NOTE: 14 data points were stored in file FONMAH6T2

NOTE: 14 X-Y pairs were stored in data file
```

NOTE: Program name : DRPOK
      Data taken by   : O'KEEFE
      This analysis done on file : FONMAH6T3
      This analysis includes end-fin effect
      Thermal conductivity   = 21.0 (W/m.K)
      Inside diameter, Di   = 13.86 (mm)
      Outside diameter, Do   = 15.35 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
      Tube material   : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

C_1 (based on Petukhov-Popov)   = 2.3616
Alpha (based on Nusselt (Tdel)) = 1.0051
Ennancement (q)   = 1.425
Enhancement (Del-T)   = 1.304

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.62	6.405E+03	1.350E+04	4.721E+05	34.97	100.05
2	3.18	6.279E+03	1.358E+04	4.601E+05	33.89	99.89
3	2.74	6.154E+03	1.383E+04	4.500E+05	32.55	100.01
4	2.29	5.949E+03	1.394E+04	4.334E+05	31.09	99.93
5	1.85	5.704E+03	1.425E+04	4.142E+05	29.06	99.89
6	1.41	5.321E+03	1.446E+04	3.857E+05	26.68	100.01
7	0.97	4.825E+03	1.557E+04	3.481E+05	22.36	100.02
8	1.41	5.333E+03	1.455E+04	3.974E+05	26.61	100.05
9	2.30	5.951E+03	1.397E+04	4.349E+05	31.14	99.91
10	3.18	6.274E+03	1.355E+04	4.611E+05	34.02	100.01

Least-Squares Line for Ho vs q curve:
  Slope   = -2.1564E-01
  Intercept = 7.6915E+05

Least-squares line for q = a*delta-T^b
  a = 3.3011E+04
  b = 7.5000E-01

NOTE: 10 data points were stored in file FONMAH6T3

NOTE: 10 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
      Data taken by   : O'KEEFE
      This analysis done on file : FONMAN6T1
      This analysis includes end-fin effect
      Thermal conductivity   = 21.0 (W/m.K)
      Inside diameter, D_i = 13.86 (mm)
      Outside diameter, Do   = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
      Tube material   : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

C_i (based on Petukhov-Popov)   =   1.1204
Alpha (based on Nusselt (Tdel)) =   1.0190
Enhancement (q)   =   1.465
Enhancement (Del-T)   =   1.331

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C
1	3.62	5.436E+03	1.471E+04	3.945E+05	25.83	99.98
2	3.17	5.295E+03	1.527E+04	3.831E+05	25.10	99.96
3	2.73	5.044E+03	1.531E+04	3.643E+05	23.79	99.91
4	2.29	4.772E+03	1.571E+04	3.446E+05	21.93	99.93
5	1.85	4.410E+03	1.601E+04	3.186E+05	19.89	100.03
6	1.41	3.939E+03	1.638E+04	2.839E+05	17.33	99.93
7	0.97	3.365E+03	1.860E+04	2.419E+05	13.01	100.02
8	1.41	3.915E+03	1.605E+04	2.937E+05	17.53	100.07
9	0.97	3.370E+03	1.881E+04	2.421E+05	12.87	99.97
10	1.85	4.404E+03	1.605E+04	3.197E+05	19.92	99.93
11	2.29	4.762E+03	1.569E+04	3.458E+05	22.04	99.91
12	2.73	5.056E+03	1.548E+04	3.669E+05	23.71	99.97
13	3.17	5.290E+03	1.523E+04	3.925E+05	25.12	99.89
14	3.62	5.472E+03	1.495E+04	3.960E+05	25.50	99.98

Least-Squares Line for Ho vs q curve:
   Slope   = -1.7416E-01
   Intercept   = 7.5469E+05

Least-squares line for q = a*delta-T^b
   a =   3.4038E+04
   b =   7.5000E-01

NOTE: 14 data points were stored in file FONMAN6T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
      Data taken by   : O'KEEFE
      This analysis done on file : FONMVH6T1
      This analysis includes end-fin effect
      Thermal conductivity   = 21.0 (W/m.K)
      Inside diameter, Di   = 13.86 (mm)
      Outside diameter, Do   = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
      Tube material   : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)   = 2.1602
Alpha (based on Nusselt (Tdel)) = 0.9498
Enhancement (q)   = 1.330
Enhancement (Del-T)   = 1.238

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C)
1	3.63	6.503E+03	1.468E+04	1.602E+05	10.92	48.76
2	3.19	6.324E+03	1.459E+04	1.530E+05	10.48	48.55
3	2.74	6.140E+03	1.468E+04	1.489E+05	10.14	48.73
4	2.30	5.961E+03	1.514E+04	1.430E+05	9.45	48.59
5	1.86	5.626E+03	1.512E+04	1.352E+05	8.94	48.75
6	0.97	4.703E+03	1.707E+04	1.099E+05	6.44	48.65
7	1.41	5.222E+03	1.549E+04	1.246E+05	8.04	48.67
8	2.30	5.930E+03	1.495E+04	1.430E+05	9.57	48.64
9	3.19	6.329E+03	1.462E+04	1.540E+05	10.53	48.67
10	1.41	5.229E+03	1.554E+04	1.241E+05	7.99	48.59

Least-Squares Line for Ho vs q curve:
  Slope   = -2.4792E-01
  Intercept   = 5.3256E+05

Least-squares line for q = a*delta-T^b
  a = 2.6385E+04
  b = 7.5000E-01

NOTE: 10 data points were stored in file FONMVH6T1

NOTE: 10 X-Y pairs were stored in data file

```
NOTE: Program name : DRPOK
      Data taken by              : O'KEEFE
      This analysis done on file : FONMVH6T2
      This analysis includes end-fin effect
      Thermal conductivity      =  21.0 (W/m.K)
      Inside diameter, Di       =  13.86 (mm)
      Outside diameter, Do      =  15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
      Tube material      : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho
```

C1 (based on Petukhov-Popov)   = 2.2144
Alpha (based on Nusselt (Tdel)) = 0.9460
Enhancement (q)   = 1.323
Enhancement (Del-T)   = 1.233

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C)
1	3.63	6.476E+03	1.438E+04	1.610E+05	11.20	48.70
2	3.19	6.318E+03	1.439E+04	1.570E+05	10.91	48.80
3	2.75	6.157E+03	1.459E+04	1.516E+05	10.39	48.64
4	2.30	5.945E+03	1.481E+04	1.454E+05	9.82	48.53
5	1.96	5.645E+03	1.498E+04	1.380E+05	9.21	48.55
6	1.42	5.228E+03	1.518E+04	1.278E+05	8.42	48.74
7	0.97	4.712E+03	1.663E+04	1.125E+05	6.77	48.55
8	1.42	5.250E+03	1.538E+04	1.297E+05	8.37	48.76
9	0.97	4.715E+03	1.567E+04	1.129E+05	6.77	48.55
10	1.86	5.635E+03	1.492E+04	1.382E+05	9.26	48.62
11	2.30	5.932E+03	1.474E+04	1.457E+05	9.88	48.56
12	2.75	6.159E+03	1.461E+04	1.523E+05	10.42	48.66
13	3.19	6.331E+03	1.447E+04	1.572E+05	10.86	48.71
14	3.63	6.490E+03	1.445E+04	1.610E+05	11.14	48.67

Least-Squares Line for Ho vs q curve:
   Slope   = -2.4920E-01
   Intercept = 5.8254E+05

Least-squares line for q = a*delta-T^b
   a = 2.6267E+04
   b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVH6T2

NOTE: 14 X-Y pairs were stored in data file

```
NOTE: Program name : DRPOK
      Data taken by              : O'KEEFE
      This analysis done on file : FONMVN6T1
      This analysis includes end-fin effect
      Thermal conductivity     = 21.0 (W/m.K)
      Inside diameter, Di       = 13.86 (mm)
      Outside diameter, Do      = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement    : WIRE-WRAPPED SMOOTH TUBE
      Tube material       : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho
```

Ci (based on Petukhov-Popov)   =   1.0427
Alpha (based on Nusselt (Tdel)) =   1.0131
Enhancement (q)   =   1.325
Enhancement (Del-T)   =   1.235

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.63	5.471E+03	1.674E+04	1.360E+05	8.12	48.58
2	3.19	5.271E+03	1.713E+04	1.308E+05	7.64	48.63
3	2.75	5.035E+03	1.768E+04	1.244E+05	7.04	48.60
4	2.30	4.697E+03	1.769E+04	1.156E+05	6.53	48.58
5	1.86	4.296E+03	1.786E+04	1.059E+05	5.93	48.72
6	1.42	3.804E+03	1.938E+04	9.333E+04	5.08	48.70
7	0.97	3.210E+03	2.134E+04	7.770E+04	3.64	48.60
8	1.42	3.800E+03	1.834E+04	9.400E+04	5.13	48.75
9	0.97	3.201E+03	2.101E+04	7.757E+04	3.69	48.56
10	1.86	4.293E+03	1.790E+04	1.070E+05	5.98	48.77
11	2.30	4.693E+03	1.771E+04	1.169E+05	6.50	48.64
12	2.75	5.044E+03	1.784E+04	1.255E+05	7.04	48.57
13	3.19	5.276E+03	1.721E+04	1.313E+05	7.63	48.53
14	3.63	5.473E+03	1.677E+04	1.370E+05	8.17	48.69

Least-Squares Line for Ho vs q curve:
  Slope   = -2.0780E-01
  Intercept = 5.7953E+05

Least-squares line for q = a*delta-T^b
  a = 2.8413E+04
  b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVN6T1

NOTE: 14 X-Y pairs were stored in data file

```
NOTE: Program name : DRPOK
      Data taken by              : O'KEEFE
      This analysis done on file : FONMAH7T1
      This analysis includes end-fin effect
      Thermal conductivity      = 21.0 (W/m.K)
      Inside diameter, Di       = 13.86 (mm)
      Outside diameter, Do      = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube      .
      Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
      Tube material      : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho
```

C1 (based on Petukhov-Popov)   =   2.2365
Alpha (based on Nusselt (Tdel)) =   0.9249
Enhancement (q)   =   1.275
Enhancement (Del-T)   =   1.200

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C
1	3.61	6.067E+03	1.223E+04	4.375E+05	35.62	99.94
2	3.17	5.979E+03	1.243E+04	4.232E+05	34.06	99.94
3	2.73	5.823E+03	1.245E+04	4.095E+05	32.90	100.11
4	2.29	5.662E+03	1.267E+04	3.948E+05	31.17	99.95
5	1.84	5.397E+03	1.271E+04	3.745E+05	29.47	100.06
6	1.40	5.073E+03	1.306E+04	3.503E+05	26.82	99.95
7	0.97	4.609E+03	1.428E+04	3.254E+05	22.79	99.97
8	1.41	5.051E+03	1.321E+04	3.535E+05	27.51	99.93
9	0.97	4.604E+03	1.446E+04	3.310E+05	22.90	99.95
10	1.41	5.045E+03	1.323E+04	3.666E+05	27.70	100.00
11	1.85	5.360E+03	1.290E+04	3.936E+05	30.52	100.09
12	2.30	5.518E+03	1.267E+04	4.123E+05	32.55	100.06
13	2.74	5.829E+03	1.265E+04	4.282E+05	33.85	100.20
14	3.18	5.974E+03	1.253E+04	4.393E+05	35.06	99.97
15	3.62	6.062E+03	1.232E+04	4.465E+05	36.24	100.05
16	3.18	5.973E+03	1.252E+04	4.383E+05	35.01	99.95
17	3.62	6.070E+03	1.235E+04	4.467E+05	36.13	100.09
18	2.74	5.845E+03	1.271E+04	4.282E+05	33.63	99.97
19	2.30	5.630E+03	1.272E+04	4.117E+05	32.37	99.99
20	1.85	5.380E+03	1.298E+04	3.922E+05	30.44	100.02

Least-Squares Line for Ho vs q curve:
  Slope   = -2.2991E-01
  Intercept = 7.6695E+05

Least-squares line for q = a*delta-T^b
  a = 3.0311E-04
  b = 7.5000E-01

NOTE: 20 data points were stored in file FONMAH7T1

NOTE: 20 X-Y pairs were stored in data file

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NOTE: Program name : DRPOST
       Data taken by   : O'KEEFE
       This analysis done on file : FONMAN7T1
       This analysis includes end-fin effect
       Thermal conductivity   = 21.0 (W/m.K)
       Inside diameter, D_i = 13.36 (mm)
       Outside diameter, D_o = 15.85 (mm)
       This analysis uses the QUARTZ THERMOMETER readings
       Modified Petukhov-Popov coefficient   = 1.0000
       Using no insert inside tube
       Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
       Tube material   : TITANIUM
       Pressure condition : ATMOSPHERIC
       Nusselt theory is used for Ho

C_i (based on Petukhov-Popov)   =   1.1913
Alpha (based on Nusselt (Tdel)) =   0.8660
Enhancement (q)   =   1.179
Enhancement (Del-T)   =   1.131

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.63	5.149E+03	1.232E+04	3.830E+05	31.09	99.96
2	3.18	4.963E+03	1.228E+04	3.679E+05	29.95	99.99
3	2.74	4.764E+03	1.240E+04	3.532E+05	28.48	100.06
4	2.30	4.500E+03	1.242E+04	3.338E+05	26.88	100.08
5	1.86	4.189E+03	1.259E+04	3.100E+05	24.63	99.98
6	1.41	3.795E+03	1.299E+04	2.809E+05	21.61	100.08
7	0.97	3.319E+03	1.507E+04	2.442E+05	16.21	99.91
8	1.41	3.786E+03	1.292E+04	2.808E+05	21.73	100.06
9	0.97	3.308E+03	1.488E+04	2.439E+05	16.39	99.97
10	1.86	4.185E+03	1.261E+04	3.113E+05	24.69	99.97
11	2.30	4.491E+03	1.240E+04	3.345E+05	26.98	100.01
12	2.74	4.764E+03	1.243E+04	3.540E+05	28.47	99.90
13	3.18	4.968E+03	1.234E+04	3.698E+05	29.97	100.03
14	3.63	5.151E+03	1.232E+04	3.831E+05	31.09	100.24

Least-Squares Line for Ho vs q curve:
  Slope   = -2.1519E-01
  Intercept = 7.5742E+05

Least-squares line for q = a*delta-T^b
  a = 2.8701E+04
  b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAN7T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DROST
      Data taken by   : O'KEEFE
      This analysis done on file : FONMVH7T2
      This analysis includes end-fin effect
      Thermal conductivity   = 21.0 (W/m.K)
      Inside diameter, Di   = 13.86 (mm)
      Outside diameter, Do   = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
      Tube material   : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)   = 1.9553
Alpha (based on Nusselt (Tdel)) = 0.8552
Enhancement (q)   = 1.156
Enhancement (Del-T)   = 1.115

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C
1	2.30	5.539E+03	1.355E+04	1.303E+05	9.61	48.63
2	1.86	5.230E+03	1.359E+04	1.219E+05	8.97	48.53
3	1.41	4.865E+03	1.405E+04	1.131E+05	8.05	48.65
4	0.97	4.349E+03	1.526E+04	1.006E+05	6.59	48.72
5	1.41	4.842E+03	1.387E+04	1.135E+05	8.18	48.72
6	1.41	4.871E+03	1.412E+04	1.136E+05	8.05	48.63
7	1.86	5.237E+03	1.365E+04	1.239E+05	9.07	48.70
8	2.30	5.516E+03	1.343E+04	1.305E+05	9.71	48.58
9	2.74	5.738E+03	1.332E+04	1.364E+05	10.25	48.64
10	3.18	5.886E+03	1.309E+04	1.408E+05	10.76	48.75
11	3.63	6.067E+03	1.320E+04	1.441E+05	10.92	48.53
12	3.18	5.872E+03	1.301E+04	1.405E+05	10.79	48.80
13	2.74	5.721E+03	1.322E+04	1.355E+05	10.25	49.65
14	2.30	5.544E+03	1.359E+04	1.307E+05	9.62	48.52

Least-Squares Line for Ho vs q curve:
   Slope   = -2.8347E-01
   Intercept = 5.8361E+05

Least-squares line for q = a*delta-T^b
   a = 2.3773E+04
   b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVH7T2

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPGT
      Data taken by   : O'KEEFE
      This analysis done on file : FONMVN7T1
      This analysis includes end-fin effect
      Thermal conductivity   = 21.0 (W/m.K)
      Inside diameter, D_i = 13.86 (mm)
      Outside diameter, D_o = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
      Tube material   : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho

C_i (based on Petukhov-Popov)   =   0.9775
Alpha (based on Nusselt (Tdel)) =   0.8700
Enhancement (q)   =   1.081
Enhancement (Del-T)   =   1.060

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C)
1	3.63	5.069E+03	1.436E+04	1.240E+05	8.64	48.53
2	3.19	4.829E+03	1.413E+04	1.180E+05	8.35	48.74
3	2.74	4.658E+03	1.490E+04	1.125E+05	7.55	48.61
4	2.30	4.341E+03	1.480E+04	1.052E+05	7.11	48.78
5	1.86	3.967E+03	1.477E+04	9.574E+04	6.48	48.81
6	1.41	3.557E+03	1.583E+04	8.537E+04	5.39	48.75
7	0.97	2.997E+03	1.783E+04	7.072E+04	3.97	48.56
8	1.41	3.562E+03	1.596E+04	8.553E+04	5.36	48.68
9	0.97	2.977E+03	1.719E+04	7.082E+04	4.12	48.67
10	1.86	3.983E+03	1.505E+04	9.639E+04	6.41	48.68
11	2.30	4.339E+03	1.490E+04	1.051E+05	7.10	48.67
12	2.74	4.633E+03	1.465E+04	1.127E+05	7.70	48.76
13	3.19	4.828E+03	1.410E+04	1.180E+05	8.37	48.85
14	3.63	5.090E+03	1.447E+04	1.238E+05	8.54	48.72

Least-Squares Line for Ho vs q curve:
   Slope   = -2.4125E-01
   Intercept = 5.7963E+05

Least-squares line for q = a*delta-T^b
   a = 2.4307E+04
   b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVN7T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DR8GK
      Data taken by   : O'KEEFE
      This analysis done on file : FONMAHLT2
      This analysis includes end-fin effect
      Thermal conductivity   = 21.0 (W/m.K)
      Inside diameter, Di   = 13.47 (mm)
      Outside diameter, Do   = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement   : LPD KORODENSE TUBE
      Tube material   : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

C_i (based on Petukhov-Popov)   = 2.9032
Alpha (based on Nusselt (Tdel)) = 0.9029
Enhancement (q)   = 1.235
Enhancement (Del-T)   = 1.171

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C
1	1.03	4.746E+03	1.321E+04	3.432E+05	25.98	100.00
2	1.49	5.182E+03	1.291E+04	3.747E+05	29.04	100.01
3	1.96	5.431E+03	1.255E+04	3.909E+05	31.14	100.05
4	2.43	5.611E+03	1.238E+04	4.029E+05	32.56	99.95
5	2.99	5.757E+03	1.231E+04	4.129E+05	33.54	99.99
6	3.36	5.842E+03	1.213E+04	4.175E+05	34.41	99.95
7	3.82	5.913E+03	1.204E+04	4.222E+05	35.07	99.99
8	3.35	5.833E+03	1.208E+04	4.143E+05	34.30	99.99
9	3.82	5.926E+03	1.206E+04	4.208E+05	34.89	100.02
10	2.89	5.755E+03	1.226E+04	4.069E+05	33.18	99.97
11	2.42	5.629E+03	1.242E+04	3.985E+05	32.09	99.95
12	1.96	5.433E+03	1.254E+04	3.881E+05	30.96	99.93
13	1.49	5.176E+03	1.282E+04	3.708E+05	29.93	100.02
14	1.03	4.765E+03	1.326E+04	3.401E+05	25.64	99.91

Least-Squares Line for Ho vs q curve:
   Slope   = -2.4802E-01
   Intercept = 7.7226E+05

Least-squares line for q = a*delta-T^b
   a = 2.9569E+04
   b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAHLT2

NOTE: 14 X-Y pairs were stored in data file

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NOTE: Program name : DRPOK
       Data taken by   : O'KEEFE
       This analysis done on file : FONMAHLT3
       This analysis includes end-fin effect
       Thermal conductivity   = 21.0 (W/m.K)
       Inside diameter, D_i = 13.47 (mm)
       Outside diameter, Do   = 15.85 (mm)
       This analysis uses the QUARTZ THERMOMETER readings
       Modified Petukhov-Popov coefficient   = 1.0000
       Using HEATEX insert inside tube
       Tube Enhancement   : LPD KORODENSE TUBE
       Tube material   : TITANIUM
       Pressure condition : ATMOSPHERIC
       Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)   = 2.8921
Alpha (based on Nusselt (Tdel)) = 0.9159
Enhancement (q)   = 1.259
Enhancement (Del-T)   = 1.188

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C)
1	3.83	5.902E+03	1.203E+04	4.313E+05	35.34	100.05
2	3.36	5.842E+03	1.219E+04	4.256E+05	34.90	99.93
3	2.90	5.778E+03	1.247E+04	4.206E+05	33.74	100.04
4	2.43	5.625E+03	1.250E+04	4.085E+05	32.67	100.01
5	1.96	5.466E+03	1.290E+04	3.958E+05	30.93	99.97
6	1.49	5.195E+03	1.302E+04	3.754E+05	28.83	99.94
7	1.03	4.782E+03	1.348E+04	3.429E+05	25.44	99.94
8	1.96	5.431E+03	1.262E+04	3.949E+05	31.29	100.03
9	2.43	5.647E+03	1.262E+04	4.114E+05	32.59	99.97
10	2.90	5.783E+03	1.250E+04	4.219E+05	33.76	99.99
11	3.83	5.929E+03	1.215E+04	4.335E+05	35.67	99.95

Least-Squares Line for Ho vs q curve:
  Slope   = -2.4475E-01
  Intercept   = 7.7234E+05

Least-squares line for q = a*delta-T^b
  a = 2.9951E+04
  b = 7.5000E-01

NOTE: 11 data points were stored in file FONMAHLT3

NOTE: 11 X-Y pairs were stored in data file

```
NOTE: Program name : DR09T
      Data taken by              : O'KEEFE
      This analysis done on file : FONMANLT2
      This analysis includes end-fin effect
      Thermal conductivity      =  21.0 (W/m.K)
      Inside diameter, Di       = 13.47 (mm)
      Outside diameter, Do      = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement   : LPD KORODENSE TUBE
      Tube material      : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho
```

Ci (based on Petukhov-Popov)   = 2.0556
Alpha (based on Nusselt (Tael)) = 0.9191
Enhancement (q)   = 1.276
Enhancement (Del-T)   = 1.201

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C
1	2.43	5.306E+03	1.317E+04	3.858E+05	29.30	99.96
2	1.96	5.055E+03	1.324E+04	3.664E+05	27.68	100.07
3	1.49	4.759E+03	1.376E+04	3.428E+05	24.91	99.88
4	1.03	4.246E+03	1.411E+04	3.054E+05	21.64	100.03
5	1.49	4.724E+03	1.350E+04	3.419E+05	25.32	99.98
6	1.03	4.253E+03	1.420E+04	3.057E+05	21.53	99.90
7	1.96	5.053E+03	1.325E+04	3.677E+05	27.74	100.05
8	2.43	5.297E+03	1.310E+04	3.847E+05	29.35	99.95
9	2.90	5.451E+03	1.293E+04	3.960E+05	30.85	99.94
10	3.36	5.578E+03	1.266E+04	4.051E+05	31.99	99.98
11	3.83	5.632E+03	1.231E+04	4.086E+05	33.20	99.87
12	3.36	5.569E+03	1.261E+04	4.042E+05	32.05	100.07
13	3.83	5.636E+03	1.232E+04	4.098E+05	33.19	100.02
14	2.89	5.460E+03	1.286E+04	3.951E+05	30.73	100.11

Least-Squares Line for Ho vs q curve:
   Slope   = -2.2863E-01
   Intercept = 7.6648E+05

Least-squares line for q = a+delta-T^b
   a = 3.0263E+04
   b = 7.5000E-01

NOTE: 14 data points were stored in file FONMANLT2

NOTE: 14 X-Y pairs were stored in data file

```
NOTE: Program name : DRFT9T
      Data taken by                 : O'KEEFE
      This analysis done on file : FONMANLT3
      This analysis includes end-fin effect
      Thermal conductivity      =  21.0 (W/m.K)
      Inside diameter, Di       = 13.47 (mm)
      Outside diameter, Do      = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement    : LPD KORODENSE TUBE
      Tube material       : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)    =   1.9930
Alpha (based on Nusselt (Tdel)) =   0.9411
Enhancement (q)                 =   1.317
Enhancement (Del-T)             =   1.230

Data    Vw       Uo          Ho          Qp          Tcf      Ts
 #     (m/s)   (W/m^2-K)   (W/m^2-K)    (W/m^2)      (C)      (C)
  1    2.43   5.283E+03   1.333E+04   3.852E+05    29.91    99.85
  2    1.96   5.049E+03   1.355E+04   3.662E+05    27.02    99.94
  3    1.49   4.761E+03   1.425E+04   3.439E+05    24.13   100.03
  4    1.03   4.246E+03   1.475E+04   3.046E+05    20.64    99.96
  5    1.49   4.751E+03   1.417E+04   3.432E+05    24.22   100.00
  6    1.03   4.253E+03   1.482E+04   3.048E+05    20.56    99.97
  7    1.96   5.078E+03   1.375E+04   3.674E+05    26.72    99.93
  8    2.43   5.316E+03   1.349E+04   3.855E+05    28.57   100.03
  9    2.89   5.464E+03   1.313E+04   3.963E+05    30.18    99.94
 10    3.36   5.593E+03   1.294E+04   4.063E+05    31.40   100.09
 11    3.83   5.564E+03   1.263E+04   4.113E+05    32.57   100.04

Least-Squares Line for Ho vs q curve:
  Slope      = -2.2725E-01
  Intercept =   7.6783E+05

Least-squares line for q = a*delta-T^b
  a =  3.1076E+04
  b =  7.5000E-01


NOTE: 11 data points were stored in file FONMANLT3

NOTE: 11 X-Y pairs were stored in data file
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NOTE: Program name : DR29T
      Data taken by   : O'KEEFE
      This analysis done on file : FONMVHLT1
      This analysis includes end-fin effect
      Thermal conductivity   = 21.0 (W/m.K)
      Inside diameter, Di   = 13.47 (mm)
      Outside diameter, Do   = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement   : LPD KORODENSE TUBE
      Tube material   : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho

C_i (based on Petukhov-Popov)   = 2.7173
Alpha (based on Nusselt (Tdel)) = 0.9449
Enhancement (q)   = 1.321
Enhancement (Del-T)   = 1.232

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C
1	1.03	4.900E+03	1.624E+04	1.195E+05	7.36	48.68
2	1.50	5.386E+03	1.546E+04	1.316E+05	8.51	48.69
3	1.97	5.700E+03	1.506E+04	1.397E+05	9.28	48.64
4	2.44	5.912E+03	1.473E+04	1.456E+05	9.89	48.73
5	2.91	6.143E+03	1.492E+04	1.503E+05	10.07	48.61
6	3.38	6.209E+03	1.442E+04	1.526E+05	10.58	48.72
7	3.84	6.311E+03	1.431E+04	1.550E+05	10.83	48.72
8	3.37	6.240E+03	1.459E+04	1.519E+05	10.41	48.63
9	3.84	6.326E+03	1.438E+04	1.543E+05	10.73	48.65
10	2.91	6.112E+03	1.472E+04	1.485E+05	10.09	48.74
11	2.44	5.937E+03	1.485E+04	1.430E+05	9.63	48.64
12	1.97	5.729E+03	1.520E+04	1.375E+05	9.05	48.70
13	1.50	5.370E+03	1.525E+04	1.277E+05	8.38	48.69
14	1.03	4.890E+03	1.597E+04	1.152E+05	7.21	48.70

Least-Squares Line for Ho vs q curve:
   Slope   = -2.6049E-01
   Intercept = 5.8423E+05

Least-squares line for q = a*delta-T^b
   a = 2.6230E+04
   b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVHLT1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DREON
        Data taken by   : O'KEEFE
        This analysis done on file : FONMVHLT2
        This analysis includes end-fin effect
        Thermal conductivity   = 21.0 (W/m.K)
        Inside diameter, Di   = 13.47 (mm)
        Outside diameter, Do   = 15.85 (mm)
        This analysis uses the QUARTZ THERMOMETER readings
        Modified Petukhov-Popov coefficient   = 1.0000
        Using HEATEX insert inside tube
        Tube Enhancement   : LPD KORODENSE TUBE
        Tube material   : TITANIUM
        Pressure condition : VACUUM
        Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)   = 2.6688
Alpha (based on Nusselt (Tdel)) = 0.9496
Enhancement (q)   = 1.329
Enhancement (Del-T)   = 1.238

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.84	6.322E+03	1.446E+04	1.542E+05	10.66	48.63
2	3.37	6.238E+03	1.469E+04	1.519E+05	10.34	48.70
3	2.91	6.078E+03	1.466E+04	1.473E+05	10.05	48.68
4	2.44	5.927E+03	1.495E+04	1.429E+05	9.56	48.63
5	1.97	5.730E+03	1.541E+04	1.371E+05	8.90	48.66
6	1.50	5.388E+03	1.565E+04	1.281E+05	8.18	48.69
7	1.03	4.878E+03	1.622E+04	1.149E+05	7.08	48.65
8	1.97	5.706E+03	1.525E+04	1.377E+05	9.03	48.68
9	2.44	5.941E+03	1.505E+04	1.442E+05	9.59	48.64
10	2.91	6.095E+03	1.477E+04	1.489E+05	10.08	48.69
11	3.94	6.329E+03	1.451E+04	1.554E+05	10.71	48.68
12	1.03	4.891E+03	1.636E+04	1.149E+05	7.02	48.63

Least-Squares Line for Ho vs q curve:
   Slope   = -2.5633E-01
   Intercept = 5.8376E+05

Least-squares line for q = a*delta-T^b
   a = 2.6375E+04
   b = 7.5000E-01

NOTE: 12 data points were stored in file FONMVHLT2

NOTE: 12 X-Y pairs were stored in data file

NOTE: Program name : DR59T
      Data taken by   : O'KEEFE
      This analysis done on file : FONMVNLT2
      This analysis includes end-fin effect
      Thermal conductivity   = 21.0 (W/m.K)
      Inside diameter, D_i = 13.47 (mm)
      Outside diameter, Do   = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement   : LPD KORODENSE TUBE
      Tube material   : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)   = 1.8686
Alpha (based on Nusselt (Tdel)) = 0.9526
Enhancement (q)   = 1.220
Enhancement (Del-T)   = 1.161

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C
1	1.03	4.198E+03	1.659E+04	1.007E+05	6.07	48.69
2	1.50	4.779E+03	1.625E+04	1.164E+05	7.16	48.67
3	1.97	5.207E+03	1.624E+04	1.296E+05	7.92	48.72
4	2.44	5.441E+03	1.550E+04	1.349E+05	8.70	48.74
5	2.91	5.660E+03	1.532E+04	1.403E+05	9.16	48.68
6	3.38	5.782E+03	1.483E+04	1.432E+05	9.66	48.64
7	3.85	5.873E+03	1.442E+04	1.455E+05	10.08	48.65
8	2.91	5.639E+03	1.552E+04	1.405E+05	9.05	48.72
9	3.85	5.894E+03	1.455E+04	1.462E+05	10.05	48.72
10	2.44	5.475E+03	1.576E+04	1.340E+05	8.51	48.60
11	1.97	5.189E+03	1.604E+04	1.270E+05	7.91	48.70
12	1.03	4.239E+03	1.736E+04	1.013E+05	5.83	48.70

Least-Squares Line for Ho vs q curve:
   Slope   = -2.5018E-01
   Intercept = 5.8313E+05

Least-squares line for q = a*delta-T^b
   a = 2.6547E+04
   b = 7.5000E-01

NOTE: 12 data points were stored in file FONMVNLT2

NOTE: 12 X-Y pairs were stored in data file

NOTE: Program name : DRBGT
       Data taken by   : O'KEEFE
       This analysis done on file : FONMVNLT3
       This analysis includes end-fin effect
       Thermal conductivity   = 21.0 (W/m.K)
       Inside diameter, D_i = 13.47 (mm)
       Outside diameter, Do   = 15.85 (mm)
       This analysis uses the QUARTZ THERMOMETER readings
       Modified Petukhov-Popov coefficient   = 1.0000
       Using no insert inside tube
       Tube Enhancement   : LPD KORODENSE TUBE
       Tube material   : TITANIUM
       Pressure condition : VACUUM
       Nusselt theory is used for Ho

C_1 (based on Petukhov-Popov)   =   1.8615
Alpha (based on Nusselt (Tdel)) =   0.9563
Enhancement (q)   =   1.226
Enhancement (Del-T)   =   1.165

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C)
1	1.50	4.781E+03	1.636E+04	1.161E+05	7.10	48.61
2	1.03	4.190E+03	1.578E+04	1.009E+05	6.02	48.64
3	1.50	4.813E+03	1.675E+04	1.177E+05	7.03	48.74
4	1.97	5.180E+03	1.604E+04	1.273E+05	7.93	48.69
5	2.44	5.470E+03	1.578E+04	1.348E+05	8.54	48.63
6	2.91	5.675E+03	1.547E+04	1.408E+05	9.10	48.72
7	3.38	5.781E+03	1.486E+04	1.434E+05	9.65	48.67
8	3.85	5.924E+03	1.477E+04	1.470E+05	9.96	48.63
9	3.38	5.781E+03	1.485E+04	1.433E+05	9.65	48.74
10	3.85	5.881E+03	1.450E+04	1.456E+05	10.04	48.70
11	2.91	5.693E+03	1.558E+04	1.397E+05	8.97	48.65
12	2.44	5.473E+03	1.579E+04	1.340E+05	8.49	48.68
13	1.97	5.198E+03	1.618E+04	1.262E+05	7.80	48.63
14	1.03	4.217E+03	1.717E+04	1.011E+05	5.99	48.67

Least-Squares Line for Ho vs q curve:
   Slope   = -2.4579E-01
   Intercept = 5.8265E+05

Least-squares line for q = a*delta-T^b
   a = 2.6648E+04
   b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVNLT3

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOST
       Data taken by   : O'KEEFE
       This analysis done on file : FONMAHL1T1
       This analysis includes end-fin effect
       Thermal conductivity   = 21.0 (W/m.K)
       Inside diameter, D_i = 13.47 (mm)
       Outside diameter, D_o = 15.85 (mm)
       This analysis uses the QUARTZ THERMOMETER readings
       Modified Petukhov-Popov coefficient   = 1.0000
       Using HEATEX insert inside tube
       Tube Enhancement   : WIRE-WRAPPED LPD KORODENSE TUBE
       Tube material   : TITANIUM
       Pressure condition : ATMOSPHERIC
       Nusselt theory is used for Ho

C_i (based on Petukhov-Popov)   = 2.6673
Alpha (based on Nusselt (Tdel)) = 0.8897
Enhancement (q)   = 1.211
Enhancement (Del-T)   = 1.154

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	2.43	5.447E+03	1.212E+04	3.997E+05	32.98	100.05
2	1.96	5.263E+03	1.230E+04	3.850E+05	31.29	99.98
3	1.50	5.002E+03	1.260E+04	3.649E+05	28.96	99.96
4	1.03	4.605E+03	1.323E+04	3.332E+05	25.19	99.87
5	1.50	4.996E+03	1.257E+04	3.648E+05	29.03	99.98
6	1.03	4.594E+03	1.315E+04	3.334E+05	25.35	99.99
7	1.96	5.251E+03	1.225E+04	3.848E+05	31.42	99.91
8	2.43	5.443E+03	1.211E+04	4.003E+05	33.05	99.98
9	2.90	5.607E+03	1.210E+04	4.124E+05	34.08	100.01
10	3.37	5.698E+03	1.193E+04	4.195E+05	35.16	100.04
11	3.83	5.767E+03	1.178E+04	4.241E+05	35.99	99.96
12	3.37	5.675E+03	1.182E+04	4.170E+05	35.27	100.02
13	3.83	5.767E+03	1.178E+04	4.243E+05	36.00	100.02
14	2.90	5.583E+03	1.198E+04	4.092E+05	34.16	100.01
15	2.43	5.445E+03	1.210E+04	3.983E+05	32.91	100.01

Least-Squares Line for Ho vs q curve:
   Slope   = -2.4945E-01
   Intercept = 7.7129E+05

Least-squares line for q = a*delta-T^b
   a = 2.9099E+04
   b = 7.5000E-01

NOTE: 15 data points were stored in file FONMAHL1T1

NOTE: 15 X-Y pairs were stored in data file

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```
NOTE: Program name : DRPOST
      Data taken by              : O'KEEFE
      This analysis done on file : FONMANL1T1
      This analysis includes end-fin effect
      Thermal conductivity      = 21.0 (W/m.K)
      Inside diameter, Di       = 13.47 (mm)
      Outside diameter, Do      = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement    : WIRE-WRAPPED LPD KORODENSE TUBE
      Tube material       : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho
```

Ci (based on Petukhov-Popov)   = 2.0362
Alpha (based on Nusselt (Tdel)) = 0.8688
Enhancement (q)   = 1.184
Enhancement (Del-T)   = 1.135

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C)
1	3.84	5.440E+03	1.152E+04	4.025E+05	34.93	99.97
2	3.37	5.362E+03	1.170E+04	3.954E+05	33.79	99.98
3	2.90	5.285E+03	1.206E+04	3.893E+05	32.28	100.07
4	2.43	5.121E+03	1.220E+04	3.752E+05	30.76	99.85
5	1.96	4.889E+03	1.230E+04	3.571E+05	29.03	99.89
6	1.49	4.591E+03	1.265E+04	3.355E+05	26.52	100.04
7	1.03	4.135E+03	1.324E+04	3.003E+05	22.69	99.96
8	1.50	4.586E+03	1.263E+04	3.359E+05	26.60	100.08
9	1.03	4.132E+03	1.322E+04	3.003E+05	22.71	99.94
10	1.96	4.891E+03	1.234E+04	3.589E+05	29.09	99.90
11	2.43	5.125E+03	1.224E+04	3.774E+05	30.83	99.95
12	2.90	5.247E+03	1.187E+04	3.866E+05	32.58	99.97
13	3.37	5.363E+03	1.171E+04	3.956E+05	33.79	99.94
14	3.84	5.447E+03	1.155E+04	4.017E+05	34.79	99.91

Least-Squares Line for Ho vs q curve:
  Slope   = -2.5035E-01
  Intercept = 7.6937E+05

Least-squares line for q = a*delta-T^b
  a = 2.8535E+04
  b = 7.5000E-01

NOTE: 14 data points were stored in file FONMANL1T1

NOTE: 14 X-Y pairs were stored in data file

```
NOTE: Program name : DR89T
      Data taken by               : O'KEEFE
      This analysis done on file : FONMVHL1T1
      This analysis includes end-fin effect
      Thermal conductivity      =  21.0 (W/m.K)
      Inside diameter, Di       = 13.47 (mm)
      Outside diameter, Do      = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement    : WIRE-WRAPPED LPD KORODENSE TUBE
      Tube material       : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho
```

C_1 (based on Petukhov-Popov)   =   2.3166
Alpha (based on Nusselt (Tdel)) =   0.8799
Enhancement (q)   =   1.201
Enhancement (Del-T)   =   1.147

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C)
1	3.84	6.001E+03	1.363E+04	1.471E+05	10.80	48.64
2	3.37	5.859E+03	1.355E+04	1.427E+05	10.53	48.66
3	2.91	5.700E+03	1.355E+04	1.390E+05	10.26	48.78
4	2.44	5.510E+03	1.360E+04	1.340E+05	9.85	48.74
5	1.97	5.275E+03	1.378E+04	1.281E+05	9.30	48.81
6	1.50	5.002E+03	1.450E+04	1.195E+05	8.24	48.54
7	1.03	4.510E+03	1.520E+04	1.074E+05	7.07	48.65
8	1.50	4.998E+03	1.448E+04	1.202E+05	8.30	48.59
9	1.03	4.507E+03	1.516E+04	1.079E+05	7.11	48.74
10	1.97	5.292E+03	1.391E+04	1.286E+05	9.24	48.60
11	2.44	5.516E+03	1.366E+04	1.347E+05	9.86	48.57
12	2.91	5.698E+03	1.355E+04	1.400E+05	10.33	48.67
13	3.38	5.863E+03	1.359E+04	1.436E+05	10.57	48.61
14	3.84	5.998E+03	1.361E+04	1.470E+05	10.79	48.59

Least-Squares Line for Ho vs q curve:
   Slope   = -2.7629E-01
   Intercept = 5.8368E+05

Least-squares line for q = a*delta-T^b
   a = 2.4437E+04
   b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVHL1T1

NOTE: 14 X-Y pairs were stored in data file

```
NOTE: Program name : DR69t
        Data taken by              : O'KEEFE
        This analysis done on file : FONMVNLlT1
        This analysis includes end-fin effect
        Thermal conductivity     = 21.0 (W/m.K)
        Inside diameter, Di      = 13.47 (mm)
        Outside diameter, Do     = 15.85 (mm)
        This analysis uses the QUARTZ THERMOMETER readings
        Modified Petukhov-Popov coefficient   = 1.0000
        Using no insert inside tube
        Tube Enhancement    : WIRE-WRAPPED LPD KORODENSE TUBE
        Tube material       : TITANIUM
        Pressure condition : VACUUM
        Nusselt theory is used for Ho
```

Ci (based on Petukhov-Popov)   =   1.7837
Alpha (based on Nusselt (Tdel)) =   0.8545
Enhancement (q)   =   1.056
Enhancement (Del-T)   =   1.041

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.38	5.480E+03	1.334E+04	1.347E+05	10.10	48.60
2	2.91	5.342E+03	1.359E+04	1.305E+05	9.60	48.56
3	2.44	5.123E+03	1.363E+04	1.255E+05	9.21	48.79
4	1.97	4.852E+03	1.377E+04	1.180E+05	8.57	48.73
5	1.50	4.519E+03	1.434E+04	1.093E+05	7.62	48.74
6	1.03	3.996E+03	1.508E+04	9.583E+04	6.35	48.67
7	1.50	4.528E+03	1.447E+04	1.096E+05	7.58	48.60
8	1.03	3.992E+03	1.504E+04	9.598E+04	6.38	48.63
9	1.97	4.854E+03	1.381E+04	1.188E+05	8.60	48.67
10	2.44	5.132E+03	1.371E+04	1.264E+05	9.22	48.74
11	2.91	5.309E+03	1.338E+04	1.307E+05	9.77	48.74
12	3.38	5.470E+03	1.327E+04	1.336E+05	10.07	48.59
13	3.84	5.597E+03	1.317E+04	1.375E+05	10.44	48.70
14	3.37	5.464E+03	1.323E+04	1.338E+05	10.11	48.70
15	3.84	5.589E+03	1.312E+04	1.371E+05	10.46	48.73

Least-Squares Line for Ho vs q curve:
   Slope   = -2.8007E-01
   Intercept = 5.8324E+05

Least-squares line for q = a*delta-T^b
   a = 2.3759E+04
   b = 7.5000E-01

NOTE: 15 data points were stored in file FONMVNLlT1

NOTE: 15 X-Y pairs were stored in data file

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NOTE: Program name : DRP2t

      Data taken by   : O'KEEFE
      This analysis done on file : FONMAHL2T1
      This analysis includes end-fin effect
      Thermal conductivity   = 21.0 (W/m.K)
      Inside diameter, D_i = 13.47 (mm)
      Outside diameter, D_o = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement   : WIRE-WRAPPED LPD KORODENSE TUBE
      Tube material   : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

C_i (based on Petukhov-Popov)   =   2.6388
Alpha (based on Nusselt (Tdel)) =   0.9089
Enhancement (q)   =   1.246
Enhancement (Del-T)   =   1.179

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C
1	3.84	5.829E+03	1.210E+04	4.313E+05	35.63	99.96
2	3.37	5.755E+03	1.223E+04	4.238E+05	34.64	99.99
3	2.90	5.641E+03	1.231E+04	4.143E+05	33.64	99.96
4	2.43	5.520E+03	1.255E+04	4.043E+05	32.23	99.99
5	1.96	5.331E+03	1.276E+04	3.892E+05	30.51	99.93
6	1.49	5.020E+03	1.281E+04	3.661E+05	29.58	100.08
7	1.03	4.643E+03	1.369E+04	3.362E+05	24.55	100.01
8	1.50	5.026E+03	1.296E+04	3.667E+05	29.51	99.96
9	1.03	4.622E+03	1.353E+04	3.356E+05	24.81	100.12
10	1.96	5.304E+03	1.261E+04	3.883E+05	30.79	99.96
11	2.43	5.494E+03	1.243E+04	4.030E+05	32.43	99.92
12	2.90	5.640E+03	1.231E+04	4.143E+05	33.66	99.37
13	3.37	5.747E+03	1.219E+04	4.229E+05	34.63	99.93
14	3.83	5.824E+03	1.207E+04	4.290E+05	35.55	100.02

Least-Squares Line for Ho vs q curve:
   Slope   = -2.4705E-01
   Intercept = 7.7249E+05

Least-squares line for q = a*delta-T^b
   a = 2.9774E+04
   b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAHL2T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRP_OKT
      Data taken by   : O'KEEFE
      This analysis done on file : FONMANL2T1
      This analysis includes end-fin effect
      Thermal conductivity   = 21.0 (W/m.K)
      Inside diameter, D1   = 13.47 (mm)
      Outside diameter, Do   = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement   : WIRE-WRAPPED LPD KORODENSE TUBE
      Tube material   : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

C1 (based on Petukhov-Popov)   = 2.0573
Alpha (based on Nusselt (Tdel)) = 0.8901
Enhancement (q)   = 1.223
Enhancement (Del-T)   = 1.163

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C)
1	3.84	5.574E+03	1.207E+04	4.108E+05	34.03	99.92
2	3.37	5.450E+03	1.207E+04	4.012E+05	33.25	99.99
3	2.90	5.330E+03	1.222E+04	3.918E+05	32.06	100.00
4	2.43	5.189E+03	1.251E+04	3.811E+05	30.46	100.04
5	1.96	4.967E+03	1.272E+04	3.639E+05	28.61	99.95
6	1.49	4.670E+03	1.313E+04	3.407E+05	25.95	99.94
7	1.03	4.182E+03	1.353E+04	3.038E+05	22.46	100.02
8	1.50	4.663E+03	1.309E+04	3.410E+05	25.04	99.95
9	1.03	4.195E+03	1.369E+04	3.052E+05	22.29	100.00
10	1.96	4.957E+03	1.267E+04	3.650E+05	28.80	100.06
11	2.43	5.165E+03	1.238E+04	3.805E+05	30.73	100.08
12	2.90	5.315E+03	1.215E+04	3.911E+05	32.19	99.93
13	3.37	5.444E+03	1.204E+04	4.019E+05	33.37	100.05
14	3.84	5.552E+03	1.197E+04	4.094E+05	34.20	99.98

Least-Squares Line for Ho vs q curve:
  Slope   = -2.4184E-01
  Intercept = 7.6857E+05

Least-squares line for q = a*delta-T^b
  a = 2.9268E+04
  b = 7.5000E-01

NOTE: 14 data points were stored in file FONMANL2T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DR2DR
      Data taken by   : O'KEEFE
      This analysis done on file : FONMVHL2T1
      This analysis includes end-fin effect
      Thermal conductivity   = 21.0 (W/m.K)
      Inside diameter, D_i = 13.47 (mm)
      Outside diameter, Do   = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement   : WIRE-WRAPPED LPD KORODENSE TUBE
      Tube material   : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho

C_i (based on Petukhov-Popov)   = 2.4253
Alpha (based on Nusselt (Tdel)) = 0.8901
Enhancement (q)   = 1.220
Enhancement (Del-T)   = 1.161

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C
1	3.85	6.075E+03	1.377E+04	1.517E+05	11.02	48.53
2	3.38	5.908E+03	1.355E+04	1.474E+05	10.87	48.68
3	2.91	5.778E+03	1.368E+04	1.436E+05	10.49	48.68
4	2.44	5.580E+03	1.367E+04	1.385E+05	10.13	48.74
5	1.97	5.372E+03	1.400E+04	1.326E+05	9.47	48.73
6	1.50	5.052E+03	1.432E+04	1.238E+05	8.64	48.71
7	1.03	4.605E+03	1.535E+04	1.113E+05	7.25	48.63
8	1.50	5.045E+03	1.428E+04	1.242E+05	8.70	48.75
9	1.03	4.591E+03	1.521E+04	1.117E+05	7.34	48.70
10	1.97	5.364E+03	1.396E+04	1.331E+05	9.54	48.69
11	2.44	5.596E+03	1.378E+04	1.398E+05	10.14	48.72
12	2.91	5.779E+03	1.370E+04	1.445E+05	10.55	48.65
13	3.38	5.881E+03	1.342E+04	1.475E+05	10.99	48.66
14	3.85	5.989E+03	1.334E+04	1.511E+05	11.33	48.77

Least-Squares Line for Ho vs q curve:
   Slope   = -2.8095E-01
   Intercept = 5.8479E+05

Least-squares line for q = a*delta-T^b
   a = 2.4663E+04
   b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVHL2T1

NOTE: 14 X-Y pairs were stored in data file

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```
NOTE: Program name : DRROKI
      Data taken by               : O'KEEFE
      This analysis done on file : FONMVNL2T1
      This analysis includes end-fin effect
      Thermal conductivity        =  21.0 (W/m.K)
      Inside diameter, Di         = 13.47 (mm)
      Outside diameter, Do        = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement    : WIRE-WRAPPED LPD KORODENSE TUBE
      Tube material       : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho
```

NOTE: Program name : DR₱ŁXT
      Data taken by   : O'KEEFE
      This analysis done on file : FONMAHL3T2
      This analysis includes end-fin effect
      Thermal conductivity   = 21.0 (W/m.K)
      Inside diameter, D_1 = 13.47 (mm)
      Outside diameter, Do   = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement   : WIRE-WRAPPED LPD KORODENSE TUBE
      Tube material   : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

C_1 (based on Petukhov-Popov)   = 2.8352
Alpha (based on Nusselt (Tdel)) = 0.9682
Enhancement (q)   = 1.355
Enhancement (Del-T)   = 1.256

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C
1	1.03	4.880E+03	1.461E+04	3.506E+05	24.00	99.94
2	1.49	5.280E+03	1.378E+04	3.824E+05	27.75	100.01
3	1.96	5.597E+03	1.371E+04	4.070E+05	29.67	100.00
4	2.43	5.793E+03	1.345E+04	4.219E+05	31.35	100.04
5	2.90	5.940E+03	1.337E+04	4.337E+05	32.45	99.99
6	3.36	6.009E+03	1.305E+04	4.397E+05	33.70	100.02
7	3.83	6.100E+03	1.297E+04	4.465E+05	34.42	99.99
8	3.36	6.014E+03	1.307E+04	4.388E+05	33.57	99.90
9	3.83	6.100E+03	1.297E+04	4.460E+05	34.39	99.95
10	2.90	5.939E+03	1.336E+04	4.326E+05	32.39	99.93
11	2.43	5.783E+03	1.344E+04	4.210E+05	31.32	100.07
12	1.96	5.597E+03	1.370E+04	4.050E+05	29.64	100.08
13	1.49	5.278E+03	1.375E+04	3.811E+05	27.73	100.04
14	1.03	4.883E+03	1.459E+04	3.492E+05	23.93	99.96

Least-Squares Line for Ho vs q curve:
   Slope   = -2.2528E-01
   Intercept = 7.6980E+05

Least-squares line for q = a*delta-T^b
   a = 3.1776E+04
   b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAHL3T2

NOTE: 14 X-Y pairs were stored in data file

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NOTE: Program name : DRP9AT
      Data taken by   : O'KEEFE
      This analysis done on file : FONMANL3T1
      This analysis includes end-fin effect
      Thermal conductivity   = 21.0 (W/m.K)
      Inside diameter, Di   = 13.47 (mm)
      Outside diameter, Do   = 15.35 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement   : WIRE-WRAPPED LPD KORODENSE TUBE
      Tube material   : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

C₁ (based on Petukhov-Popov)   =   2.2023
Alpha (based on Nusselt (Tdel)) =   0.9330
Ennancement (q)   =   1.302
Ennancement (Del-T)   =   1.219

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C)
1	3.83	5.767E+03	1.262E+04	4.229E+05	33.50	99.98
2	3.36	5.682E+03	1.279E+04	4.139E+05	32.36	99.92
3	2.90	5.564E+03	1.297E+04	4.050E+05	31.23	100.07
4	2.43	5.398E+03	1.312E+04	3.908E+05	29.73	99.90
5	1.96	5.197E+03	1.348E+04	3.759E+05	27.89	100.00
6	1.49	4.867E+03	1.370E+04	3.519E+05	25.63	100.12
7	1.03	4.390E+03	1.423E+04	3.154E+05	22.09	100.03
8	1.49	4.877E+03	1.380E+04	3.523E+05	25.53	99.90
9	1.03	4.398E+03	1.438E+04	3.160E+05	21.97	99.95
10	1.96	5.189E+03	1.344E+04	3.763E+05	28.00	99.96
11	2.43	5.394E+03	1.311E+04	3.924E+05	29.93	100.02
12	2.90	5.558E+03	1.294E+04	4.045E+05	31.25	99.91
13	3.36	5.663E+03	1.259E+04	4.127E+05	32.51	99.97
14	3.83	5.776E+03	1.265E+04	4.211E+05	33.30	100.01

Least-Squares Line for Ho vs q curve:
   Slope   = -2.2985E-01
   Intercept = 7.6779E+05

Least-squares line for q = a*delta-T^b
   a = 3.0712E+04
   b = 7.5000E-01

NOTE: 14 data points were stored in file FONMANL3T1

NOTE: 14 X-Y pairs were stored in data file

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```
NOTE: Program name : DRPOK
      Data taken by               : O'KEEFE
      This analysis done on file : FONMVHL3T1
      This analysis includes end-fin effect
      Thermal conductivity      =  21.0 (W/m.K)
      Inside diameter, Di      =  13.47 (mm)
      Outside diameter, Do     =  15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement    : WIRE-WRAPPED LPD KORODENSE TUBE
      Tube material       : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho
```

C_i (based on Petukhov-Popov)   = 2.6094
Alpha (based on Nusselt (Tdel)) = 0.9949
Enhancement (q)   = 1.415
Enhancement (Del-T)   = 1.297

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C
1	3.84	6.544E+03	1.561E+04	1.570E+05	9.93	48.61
2	3.37	6.381E+03	1.565E+04	1.525E+05	9.75	48.70
3	2.90	6.240E+03	1.580E+04	1.481E+05	9.38	48.68
4	2.43	6.057E+03	1.598E+04	1.425E+05	8.91	48.60
5	1.97	5.839E+03	1.645E+04	1.370E+05	8.33	48.63
6	1.50	5.451E+03	1.649E+04	1.268E+05	7.69	48.65
7	1.03	4.959E+03	1.761E+04	1.151E+05	6.54	48.75
8	1.50	5.441E+03	1.642E+04	1.271E+05	7.74	48.62
9	1.03	4.961E+03	1.764E+04	1.146E+05	6.50	48.63
10	1.97	5.781E+03	1.603E+04	1.367E+05	8.53	48.65
11	2.43	6.023E+03	1.577E+04	1.431E+05	9.07	48.62
12	2.90	6.221E+03	1.568E+04	1.483E+05	9.45	48.65
13	3.37	6.393E+03	1.572E+04	1.529E+05	9.73	48.67
14	3.34	6.490E+03	1.549E+04	1.554E+05	10.03	48.74

Least-Squares Line for Ho vs q curve:
   Slope   = -2.3649E-01
   Intercept = 5.8263E+05

Least-squares line for q = a*delta-T^b
   a = 2.7690E+04
   b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVHL3T1

NOTE: 14 X-Y pairs were stored in data file

```
NOTE: Program name : DRPOK
      Data taken by                 : O'KEEFE
      This analysis done on file : FONMVNL3T1
      This analysis includes end-fin effect
      Thermal conductivity      = 21.0 (W/m.K)
      Inside diameter, Di       = 13.47 (mm)
      Outside diameter, Do      = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement    : WIRE-WRAPPED LPD KORODENSE TUBE
      Tube material       : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho
```

C₁ (based on Petukhov-Popov)   =   2.0410
Alpha (based on Nusselt (Tdel)) =   0.9419
Enhancement (q)   =   1.202
Enhancement (Del-T)   =   1.148

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.37	5.954E+03	1.506E+04	1.438E+05	9.55	48.73
2	3.84	6.043E+03	1.469E+04	1.462E+05	9.95	48.77
3	3.37	5.937E+03	1.494E+04	1.424E+05	9.53	48.67
4	3.84	6.031E+03	1.461E+04	1.443E+05	9.87	48.59
5	2.90	5.754E+03	1.493E+04	1.373E+05	9.20	48.68
6	2.43	5.565E+03	1.523E+04	1.330E+05	8.73	48.74
7	1.97	5.292E+03	1.543E+04	1.254E+05	8.13	48.68
8	1.50	4.917E+03	1.576E+04	1.158E+05	7.35	48.68
9	1.03	4.397E+03	1.686E+04	1.032E+05	6.12	48.73
10	1.50	4.940E+03	1.602E+04	1.172E+05	7.31	48.73
11	1.03	4.393E+03	1.682E+04	1.032E+05	6.13	48.72
12	1.97	5.295E+03	1.548E+04	1.265E+05	8.17	48.67
13	2.44	5.561E+03	1.522E+04	1.334E+05	8.77	48.61
14	2.90	5.771E+03	1.507E+04	1.388E+05	9.21	48.66

```
Least-Squares Line for Ho vs q curve:
  Slope     = -2.5211E-01
  Intercept =  5.8301E+05

Least-squares line for q = a*delta-T^b
  a =  2.6202E+04
  b =  7.5000E-01


NOTE: 14 data points were stored in file FONMVNL3T1

NOTE: 14 X-Y pairs were stored in data file
```

177

NOTE: Program name : DRPSV
      Data taken by   : O'KEEFE
      This analysis done on file : FONMAHC1
      This analysis includes end-fin effect
      Thermal conductivity   = 385.0 (W/m.K)
      Inside diameter, Di   = 12.70 (mm)
      Outside diameter, Do   = 19.05 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement   : SMOOTH TUBE
      Tube material   : COPPER
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

C_i (based on Petukhov-Popov)   =   2.8085
Alpha (based on Nusselt (Tdel)) =   0.8318
Enhancement (q)   =   1.049
Enhancement (Del-T)   =   1.037

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.31	6.736E+03	9.034E+03	4.860E+05	53.80	99.89
2	3.78	6.667E+03	9.157E+03	4.792E+05	52.33	100.04
3	3.25	6.574E+03	9.307E+03	4.697E+05	50.47	100.02
4	2.73	6.427E+03	9.463E+03	4.576E+05	48.35	99.97
5	2.20	6.207E+03	9.636E+03	4.405E+05	45.72	99.99
6	1.68	5.880E+03	9.868E+03	4.160E+05	42.16	100.03
7	1.15	5.439E+03	1.049E+04	3.803E+05	36.24	99.98
8	4.30	6.855E+03	9.234E+03	4.898E+05	53.04	99.94
9	3.77	6.785E+03	9.358E+03	4.794E+05	51.23	99.88
10	3.25	6.684E+03	9.498E+03	4.669E+05	49.37	99.96
11	2.72	6.501E+03	9.564E+03	4.541E+05	47.39	100.03
12	2.20	6.290E+03	9.787E+03	4.380E+05	44.75	100.11
13	1.67	5.971E+03	1.005E+04	4.128E+05	41.07	100.05
14	1.15	5.504E+03	1.065E+04	3.783E+05	35.53	100.04
15	2.20	6.310E+03	9.845E+03	4.402E+05	44.72	99.94
16	3.25	6.682E+03	9.491E+03	4.686E+05	49.37	100.05
17	4.29	6.868E+03	9.235E+03	4.825E+05	52.26	100.12

Least-Squares Line for Ho vs q curve:
  Slope   = -3.4308E-01
  Intercept = 7.5868E+05

Least-squares line for q = a*delta-T^b
  a = 2.5131E+04
  b = 7.5000E-01

NOTE: 17 data points were stored in file FONMAHC1

NOTE: 17 X-Y pairs were stored in data file

178

NOTE: Program name : DB2QK
       Data taken by   : O'KEEFE
       This analysis done on file : FONMANC1
       This analysis includes end-fin effect
       Thermal conductivity   = 385.0 (W/m.K)
       Inside diameter, Di   = 12.70 (mm)
       Outside diameter, Do   = 19.05 (mm)
       This analysis uses the QUARTZ THERMOMETER readings
       Modified Petukhov-Popov coefficient   = 1.0000
       Using no insert inside tube
       Tube Enhancement   : SMOOTH TUBE
       Tube material   : COPPER
       Pressure condition : ATMOSPHERIC
       Nusselt theory is used for Ho

C_1 (based on Petukhov-Popov)   =   1.2653
Alpha (based on Nusselt (Tdel)) =   0.8158
Enhancement (q)   =   1.052
Enhancement (Del-T)   =   1.039

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.31	5.764E+03	9.703E+03	4.227E+05	43.56	99.92
2	3.79	5.643E+03	9.971E+03	4.120E+05	41.32	99.98
3	3.26	5.386E+03	9.971E+03	3.929E+05	39.40	100.05
4	2.73	5.144E+03	1.024E+04	3.749E+05	36.60	99.99
5	2.21	4.827E+03	1.058E+04	3.505E+05	33.13	99.92
6	1.68	4.341E+03	1.073E+04	3.157E+05	29.42	100.02
7	1.16	3.805E+03	1.203E+04	2.757E+05	22.92	100.02
8	1.68	4.344E+03	1.079E+04	3.172E+05	29.41	100.00
9	1.16	3.804E+03	1.205E+04	2.757E+05	22.89	99.94
10	2.21	4.812E+03	1.059E+04	3.521E+05	33.36	100.00
11	2.73	5.157E+03	1.031E+04	3.772E+05	36.57	99.95
12	3.26	5.374E+03	9.959E+03	3.939E+05	39.56	99.97
13	3.79	5.643E+03	9.988E+03	4.137E+05	41.41	99.95
14	4.31	5.762E+03	9.693E+03	4.224E+05	43.58	99.99

Least-Squares Line for Ho vs q curve:
   Slope   = -2.8166E-01
   Intercept = 7.2938E+05

Least-squares line for q = a*delta-T^b
   a = 2.5317E+04
   b = 7.5000E-01

NOTE: 14 data points were stored in file FONMANC1

NOTE: 14 X-Y pairs were stored in data file

179

NOTE: Program name : DRPO8T
      Data taken by   : O'KEEFE
      This analysis done on file : FONMVHC1
      This analysis includes end-fin effect
      Thermal conductivity   = 365.0 (W/m.K)
      Inside diameter, D_i = 12.70 (mm)
      Outside diameter, Do   = 19.05 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement   : SMOOTH TUBE
      Tube material   : COPPER
      Pressure condition : VACUUM
      Nusselt theory is used for Ho

C_i (based on Petukhov-Popov)   = 2.4815
Alpha (based on Nusselt (Tdel)) = 0.8379
Enhancement (q)   =   .958
Enhancement (Del-T)   =   .968

Data	Vw	Uc	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C
1	4.32	7.579E+03	1.110E+04	1.749E+05	15.75	48.74
2	3.79	7.327E+03	1.098E+04	1.683E+05	15.32	48.69
3	3.26	7.140E+03	1.110E+04	1.631E+05	14.69	48.63
4	2.74	6.907E+03	1.128E+04	1.575E+05	13.98	48.63
5	2.21	6.573E+03	1.144E+04	1.492E+05	13.04	48.63
6	1.68	6.158E+03	1.185E+04	1.399E+05	11.81	48.72
7	1.16	5.538E+03	1.251E+04	1.248E+05	9.90	48.73

Least-Squares Line for Ho vs q curve:
   Slope   = -3.2813E-01
   Intercept = 5.5448E+05

Least-squares line for q = a*delta-T^b
   a = 2.1921E+04
   b = 7.5000E-01

NOTE: 07 data points were stored in file FONMVHC1

NOTE: 07 X-Y pairs were stored in data file

```
NOTE: Program name : DRT8I
      Data taken by              : O'KEEFE
      This analysis done on file : FONMVNC1
      This analysis includes end-fin effect
      Thermal conductivity      = 385.0 (W/m.K)
      Inside diameter, Di       = 12.70 (mm)
      Outside diameter, Do      = 19.05 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement    : SMOOTH TUBE
      Tube material       : COPPER
      Pressure condition : VACUUM
      Nusselt theory is used for Ho
```

C1 (based on Petukhov-Popov)   = 1.0947
Alpha (based on Nusselt (Tdel)) = 0.8663
Enhancement (q)   =   .942
Enhancement (Del-T)   =   .956

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.32	6.182E+03	1.238E+04	1.461E+05	11.80	48.63
2	3.79	5.937E+03	1.255E+04	1.401E+05	11.16	48.64
3	3.27	5.646E+03	1.277E+04	1.336E+05	10.48	48.77
4	2.74	5.290E+03	1.301E+04	1.252E+05	9.63	48.73
5	2.21	4.865E+03	1.339E+04	1.144E+05	8.54	48.71
6	1.68	4.309E+03	1.379E+04	1.009E+05	7.32	48.64
7	1.16	3.641E+03	1.540E+04	8.492E+04	5.51	48.62
8	1.69	4.323E+03	1.399E+04	1.023E+05	7.31	48.67
9	1.16	3.537E+03	1.533E+04	8.518E+04	5.56	48.73
10	2.21	4.811E+03	1.306E+04	1.151E+05	8.32	48.74
11	2.74	5.290E+03	1.305E+04	1.254E+05	9.68	48.68
12	3.27	5.637E+03	1.276E+04	1.353E+05	10.60	48.75
13	3.79	5.915E+03	1.248E+04	1.406E+05	11.26	48.69
14	4.32	6.186E+03	1.240E+04	1.470E+05	11.85	48.64

Least-Squares Line for Ho vs q curve:
  Slope   = -2.7240E-01
  Intercept = 5.4643E+05

Least-squares line for q = a*delta-T^b
  a = 2.2394E+04
  b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVNC1

NOTE: 14 K-Y pairs were stored in data file

181

```
NOTE: Program name : DRPOK
      Data taken by                 : O'KEEFE
      This analysis done on file : FONMAH68C1
      This analysis includes end-fin effect
      Thermal conductivity      = 385.0 (W/m.K)
      Inside diameter, Di       = 12.70 (mm)
      Outside diameter, Do      = 19.05 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement    : WIRE-WRAPPED SMOOTH TUBE
      Tube material       : COPPER
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)    =  2.8065
Alpha (based on Nusselt (Tdel)) =  1.2643
Enhancement (q)                 =  1.934
Enhancement (Del-T)             =  1.640
```

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C
1	4.29	9.492E+03	1.466E+04	6.577E+05	44.87	100.04
2	3.76	9.328E+03	1.488E+04	6.388E+05	42.93	99.97
3	3.24	9.132E+03	1.522E+04	6.213E+05	40.83	99.96
4	2.72	8.827E+03	1.553E+04	5.975E+05	38.48	99.92
5	2.19	8.375E+03	1.581E+04	5.666E+05	35.84	100.01
6	1.67	7.795E+03	1.637E+04	5.249E+05	32.06	100.02
7	1.15	6.985E+03	1.771E+04	4.679E+05	26.42	100.07
8	1.67	7.804E+03	1.647E+04	5.292E+05	32.13	100.00
9	1.15	6.992E+03	1.776E+04	4.684E+05	26.37	100.08
10	2.20	8.478E+03	1.623E+04	5.785E+05	35.64	100.01
11	2.72	8.949E+03	1.593E+04	6.088E+05	38.21	99.92
12	3.24	9.254E+03	1.559E+04	6.313E+05	40.50	100.01
13	3.76	9.531E+03	1.537E+04	6.466E+05	42.06	99.95
14	4.28	9.743E+03	1.520E+04	6.612E+05	43.50	99.97

```
Least-Squares Line for Ho vs q curve:
   Slope      = -1.9114E-01
   Intercept  =  7.3487E+05

Least-squares line for q = a*delta-T^b
   a =  3.9079E+04
   b =  7.5000E-01


NOTE: 14 data points were stored in file FONMAH68C1

NOTE: 14 X-Y pairs were stored in data file
```

182

```
NOTE: Program name : DRPOK
      Data taken by              : O'KEEFE
      This analysis done on file : FONMAN68C1
      This analysis includes end-fin effect
      Thermal conductivity       = 385.0 (W/m.K)
      Inside diameter, Di        = 12.70 (mm)
      Outside diameter, Do       = 19.05 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
      Tube material      : COPPER
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho
```

Ci (based on Petukhov-Popov)   =   1.2431
Alpha (based on Nusselt (Tdel)) =   1.3159
Enhancement (q)   =   2.059
Enhancement (Del-T)   =   1.719

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C)
1	4.29	7.797E+03	1.712E+04	5.462E+05	31.90	100.00
2	3.77	7.478E+03	1.747E+04	5.242E+05	30.00	100.03
3	3.25	7.128E+03	1.807E+04	4.989E+05	27.61	99.95
4	2.72	6.596E+03	1.812E+04	4.635E+05	25.58	99.99
5	2.20	5.980E+03	1.823E+04	4.200E+05	23.05	100.02
6	1.68	5.287E+03	1.914E+04	3.723E+05	19.45	100.04
7	1.15	4.502E+03	2.354E+04	3.170E+05	13.47	100.10
8	1.68	5.263E+03	1.901E+04	3.730E+05	19.62	100.01
9	1.15	4.450E+03	2.252E+04	3.153E+05	14.00	100.04
10	2.20	6.006E+03	1.874E+04	4.275E+05	22.81	99.95
11	2.73	6.655E+03	1.877E+04	4.724E+05	25.17	99.68
12	3.25	7.209E+03	1.878E+04	5.113E+05	27.23	99.99
13	3.77	7.658E+03	1.862E+04	5.423E+05	29.12	99.37
14	4.30	8.034E+03	1.837E+04	5.663E+05	30.83	100.02

Least-Squares Line for Ho vs q curve:
  Slope   = -1.3433E-01
  Intercept = 7.1006E+05

Least-squares line for q = a*delta-T^b
  a = 4.1757E+04
  b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAN68C1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
       Data taken by   : O'KEEFE
       This analysis done on file : FONMVH68C1
       This analysis includes end-fin effect
       Thermal conductivity   = 385.0 (W/m.K)
       Inside diameter, Di   = 12.70 (mm)
       Outside diameter, Do   = 19.05 (mm)
       This analysis uses the QUARTZ THERMOMETER readings
       Modified Petukhov-Popov coefficient   = 1.0000
       Using HEATEX insert inside tube
       Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
       Tube material   : COPPER
       Pressure condition : VACUUM
       Nusselt theory is used for Ho

C₁ (based on Petukhov-Popov)   = 2.5490
Alpha (based on Nusselt (Tdel)) = 1.1854
Enhancement (q)   = 1.787
Enhancement (Del-T)   = 1.546

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C
1	4.32	9.811E+03	1.641E+04	2.246E+05	13.69	48.74
2	3.79	9.448E+03	1.628E+04	2.148E+05	13.19	48.81
3	3.26	9.165E+03	1.658E+04	2.062E+05	12.43	48.78
4	2.73	8.699E+03	1.660E+04	1.946E+05	11.72	48.77
5	2.21	8.209E+03	1.703E+04	1.826E+05	10.72	48.72
6	1.68	7.523E+03	1.755E+04	1.668E+05	9.51	48.76
7	1.15	6.670E+03	1.944E+04	1.451E+05	7.46	48.62
8	1.68	7.515E+03	1.754E+04	1.687E+05	9.62	48.81
9	1.15	6.668E+03	1.946E+04	1.455E+05	7.48	48.55
10	2.21	8.220E+03	1.713E+04	1.848E+05	10.79	48.53
11	2.74	8.740E+03	1.678E+04	1.968E+05	11.73	48.59
12	3.26	9.189E+03	1.668E+04	2.073E+05	12.43	48.63
13	3.79	9.446E+03	1.627E+04	2.139E+05	13.15	48.74
14	4.31	9.846E+03	1.649E+04	2.212E+05	13.42	48.60

Least-Squares Line for Ho vs q curve:
   Slope   = -2.0791E-01
   Intercept   = 5.4980E+05

Least-squares line for q = a*delta-T^b
   a = 3.1228E+04
   b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVH68C1

NOTE: 14 X-Y pairs were stored in data file

```
NOTE: Program name : DRPOK
      Data taken by               : O'KEEFE
      This analysis done on file : FONMVN68C1
      This analysis includes end-fin effect
      Thermal conductivity      = 385.0 (W/m.K)
      Inside diameter, Di        = 12.70 (mm)
      Outside diameter, Do       = 19.05 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement    : WIRE-WRAPPED SMOOTH TUBE
      Tube material       : COPPER
      Pressure condition : VACUUM
      Nusselt theory is used for Ho
```

Ci (based on Petukhov-Popov)   = 1.0378
Alpha (based on Nusselt (Tdel)) = 1.2885
Enhancement (q)   = 1.825
Enhancement (Del-T)   = 1.570

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C)
1	4.32	7.410E+03	1.953E+04	1.749E+05	8.93	48.82
2	3.79	7.037E+03	1.994E+04	1.644E+05	8.24	48.70
3	3.26	6.671E+03	2.102E+04	1.549E+05	7.37	48.66
4	2.74	6.177E+03	2.189E+04	1.432E+05	6.54	48.63
5	2.21	5.557E+03	2.262E+04	1.288E+05	5.69	48.61
6	1.68	4.800E+03	2.340E+04	1.111E+05	4.75	48.60
7	1.16	3.882E+03	2.496E+04	8.997E+04	3.60	48.78
8	1.68	4.765E+03	2.277E+04	1.127E+05	4.95	48.81
9	1.16	3.877E+03	2.492E+04	8.988E+04	3.61	48.63
10	2.21	5.572E+03	2.308E+04	1.316E+05	5.70	48.67
11	2.74	6.155E+03	2.177E+04	1.446E+05	6.64	48.55
12	3.27	6.643E+03	2.086E+04	1.567E+05	7.51	48.66
13	3.79	7.016E+03	1.981E+04	1.647E+05	8.31	48.67
14	4.32	7.407E+03	1.954E+04	1.746E+05	8.94	48.85
15	2.74	6.165E+03	2.172E+04	1.423E+05	6.55	48.58
16	1.16	3.896E+03	2.523E+04	8.882E+04	3.52	48.70

Least-Squares Line for Ho vs q curve:
   Slope   = -1.6323E-01
   Intercept = 5.4549E+05

Least-squares line for q = a*delta-T^b
   a = 3.4454E+04
   b = 7.5000E-01

NOTE: 16 data points were stored in file FONMVN68C1

NOTE: 16 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
        Data taken by   : O'KEEFE
        This analysis done on file : FONMAH71C1
        This analysis includes end-fin effect
        Thermal conductivity   = 385.0 (W/m.K)
        Inside diameter, D_1 = 12.70 (mm)
        Outside diameter, Do   = 19.05 (mm)
        This analysis uses the QUARTZ THERMOMETER readings
        Modified Petukhov-Popov coefficient   = 1.0000
        Using HEATEX insert inside tube
        Tube Enhancement   : SMOOTH TUBE
        Tube material   : COPPER
        Pressure condition : ATMOSPHERIC
        Nusselt theory is used for Ho

C_1 (based on Petukhov-Popov)   =   3.0634
Alpha (based on Nusselt (Tdel)) =   1.5049
Enhancement (q)   =   2.313
Enhancement (Del-T)   =   1.875

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C
1	4.29	1.097E+04	1.770E+04	7.469E+05	42.20	99.96
2	3.76	1.075E+04	1.796E+04	7.258E+05	40.42	99.96
3	3.24	1.050E+04	1.835E+04	7.052E+05	38.42	99.99
4	2.72	1.007E+04	1.860E+04	6.764E+05	36.37	99.97
5	2.19	9.574E+03	1.911E+04	6.407E+05	33.53	99.94
6	1.67	8.871E+03	1.986E+04	5.945E+05	29.34	100.00
7	1.15	7.842E+03	2.121E+04	5.237E+05	24.63	99.94
8	1.67	8.895E+03	2.011E+04	6.029E+05	29.37	99.92
9	1.15	7.902E+03	2.174E+04	5.310E+05	24.43	100.03
10	2.20	9.301E+03	2.017E+04	6.671E+05	33.06	100.00
11	2.72	1.039E+04	1.979E+04	7.079E+05	35.77	99.96
12	3.24	1.090E+04	1.970E+04	7.425E+05	37.63	100.37

Least-Squares Line for Ho vs q curve:
  Slope   = -1.4745E-01
  Intercept = 7.2637E+05

Least-squares line for q = a*delta-T^b
  a = 4.6853E+04
  b = 7.5000E-01

NOTE: 12 data points were stored in file FONMAH71C1

NOTE: 12 X-Y pairs were stored in data file

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```
NOTE: Program name : ORPOK
      Data taken by              : O'KEEFE
      This analysis done on file : FONMAN71C1
      This analysis includes end-fin effect
      Thermal conductivity      = 385.0 (W/m.K)
      Inside diameter, Di       = 12.70 (mm)
      Outside diameter, Do      = 19.05 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
      Tube material      : COPPER
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho


C1 (based on Petukhov-Popov)    =  1.2583
Alpha (based on Nusselt (Tdel)) =  1.7215
Enhancement (q)                 =  2.847
Enhancement (Del-T)             =  2.132
```

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.29	8.928E+03	2.330E+04	6.214E+05	25.67	99.87
2	3.77	8.523E+03	2.393E+04	5.928E+05	24.77	100.01
3	3.25	8.042E+03	2.471E+04	5.581E+05	22.59	99.93
4	2.72	7.374E+03	2.471E+04	5.131E+05	20.77	99.94
5	2.20	6.613E+03	2.490E+04	4.625E+05	18.57	100.05
6	1.68	5.750E+03	2.532E+04	4.028E+05	15.54	99.99
7	1.15	4.766E+03	3.095E+04	3.333E+05	12.77	99.95
8	1.68	5.724E+03	2.502E+04	4.054E+05	15.70	100.09
9	1.15	4.874E+03	3.643E+04	3.414E+05	9.40	100.10
10	2.20	6.652E+03	2.605E+04	4.720E+05	18.12	100.04
11	2.73	7.500E+03	2.659E+04	5.292E+05	19.90	100.03
12	3.25	8.213E+03	2.671E+04	5.778E+05	21.64	100.10
13	3.77	8.881E+03	2.713E+04	6.202E+05	22.85	99.99
14	4.29	9.435E+03	2.704E+04	6.561E+05	24.27	99.99

```
Least-Squares Line for Ho vs q curve:
  Slope     = -8.8527E-02
  Intercept =  7.0340E+05

Least-squares line for q = a*delta-T^b
  a = 5.5185E+04
  b = 7.5000E-01


NOTE: 14 data points were stored in file FONMAN71C1

NOTE: 14 X-Y pairs were stored in data file
```

NOTE: Program name : DRPOK
      Data taken by   : O'KEEFE
      This analysis done on file : FONMVN71C1
      This analysis includes end-fin effect
      Thermal conductivity   = 385.0 (W/m.K)
      Inside diameter, D_i = 12.70 (mm)
      Outside diameter, Do   = 19.05 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
      Tube material   : COPPER
      Pressure condition : VACUUM
      Nusselt theory is used for Ho

C_i (based on Petukhov-Popov)   =   1.0883
Alpha (based on Nusselt (Tdel)) =   1.4135
Enhancement (q)   =   1.809
Enhancement (Del-T)   =   1.560

Data	Vw	Uo	Ho	Qp	Tcf	Ts
#	(m/s)	(W/m^2-K)	(W/m^2-K)	(W/m^2)	(C)	(C
1	4.32	7.865E+03	2.150E+04	1.844E+05	8.58	48.55
2	3.79	7.432E+03	2.168E+04	1.751E+05	6.07	48.74
3	3.26	7.045E+03	2.292E+04	1.647E+05	7.18	48.71
4	2.74	6.532E+03	2.410E+04	1.529E+05	6.35	48.78
5	2.21	5.872E+03	2.512E+04	1.376E+05	5.48	48.63
6	1.68	5.029E+03	2.523E+04	1.187E+05	4.70	48.74
7	1.16	4.068E+03	2.738E+04	9.574E+04	3.50	48.73
8	1.68	5.056E+03	2.616E+04	1.204E+05	4.50	48.69
9	1.16	4.073E+03	2.775E+04	9.599E+04	3.46	48.69
10	2.21	5.881E+03	2.559E+04	1.402E+05	5.48	48.58
11	2.74	6.521E+03	2.427E+04	1.563E+05	6.44	48.67
12	3.27	7.074E+03	2.350E+04	1.693E+05	7.21	48.61
13	3.79	7.497E+03	2.238E+04	1.302E+05	8.05	48.92
14	4.32	7.370E+03	2.160E+04	1.882E+05	8.71	48.33

Least-Squares Line for Ho vs q curve:
   Slope   = -1.4850E-01
   Intercept = 5.4553E+05

Least-squares line for q = a*delta-T^b
   a = 3.7811E+04
   b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVN71C1

NOTE: 14 X-Y pairs were stored in data file

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```
NOTE: Program name : DRPOK
      Data taken by            : O'KEEFE
      This analysis done on file : FONMVH71C2
      This analysis includes end-fin effect
      Thermal conductivity     = 385.0 (W/m.K)
      Inside diameter, Di       = 12.70 (mm)
      Outside diameter, Do      = 19.05 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement     : WIRE-WRAPPED SMOOTH TUBE
      Tube material        : COPPER
      Pressure condition : VACUUM
      Nusselt theory is used for Ho
```

C_i (based on Petukhov-Popov)   =   2.7647
Alpha (based on Nusselt (Tdel)) =   1.2803
Enhancement (q)   =   1.636
Enhancement (Del-T)   =   1.479

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	1.16	7.118E+03	2.072E+04	1.583E+05	7.64	48.64
2	1.68	8.035E+03	1.882E+04	1.832E+05	9.73	48.77
3	2.21	8.775E+03	1.833E+04	2.015E+05	10.99	48.69
4	2.74	9.287E+03	1.784E+04	2.147E+05	12.03	48.73
5	3.26	9.855E+03	1.805E+04	2.262E+05	12.53	48.55
6	3.79	1.015E+04	1.766E+04	2.354E+05	13.33	48.75
7	4.32	1.038E+04	1.736E+04	2.413E+05	13.90	48.79
8	3.26	9.850E+03	1.802E+04	2.245E+05	12.46	48.60
9	2.21	8.857E+03	1.865E+04	1.992E+05	10.66	48.55
10	1.16	7.142E+03	2.089E+04	1.571E+05	7.53	48.57

```
Least-Squares Line for Ho vs q curve:
   Slope       = -1.9477E-01
   Intercept = 5.5020E+05

Least-squares line for q = a*delta-T^b
   a = 3.3765E+04
   b = 7.5000E-01


NOTE: 10 data points were stored in file FONMVH71C2

NOTE: 10 X-Y pairs were stored in data file
```

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APPENDIX E. DRPOK PROGRAM LISTING

The program DRPOK, which was used to collect and reprocess all of the data, is listed in this appendix.

```
100! DRPOK (O'KEEFE)
106! REVISED FROM DRP12B:   JUL 1992 (S. MEMORY)
107!
108! TO BE USED WITH NON-INSTRUMENTED TUBES ONLY
109! TAKES DATA IN THE FORMAT OF SWENSEN/O'KEEFE
110! CAN REPROCESS ANY NON-INSTRUMENTED DATA
112!
113! THIS PROGRAM WAS USED TO COLLECT ALL THE NON-
114! INSTRUMENTED DATA TAKEN BY O'KEEFE (APR-SEP 1992) FOR TITANIUM TUBES
115!
017!      MEANING OF ALL FLAGS IN PROGRAM
018!
019!      IFT:    FLUID TYPE
020!      ISO:    OPTION WITHIN PROGRAM
021!      IM:     INPUT MODE
022!      IWIL:   VALUE OF C1 USED
023!      IFG:    FINNED OR SMOOTH
024!      INN:    INSERT TYPE
025!      IWT:    LOOP NO. WITHIN PROGRAM
026!      IWTH:   ALTERNATIVE CONDENSER TUBES
027!      IMC:    TUBE MATERIAL
028!      ITDS:   TUBE DIAMETER
029!      IPC:    PRESSURE CONDITION
030!      INF:    DIMENSIONLESS FILE REQUIRED
031!      IPF:    PLOT FILE REQUIRED
032!      IOV:    OUTPUT REQUIRED
033!      IHI:    INSIDE HTC CORRELATION
034!      IOC:    OUTSIDE HTC THEORY/CORRELATION
035   COM /Cc/ C(7)
036   COM /Cc55/ T55(5)
037   COM /Cc56/ T56(5)
038   COM /Cc57/ T57(5)
039   COM /Cc58/ T58(5)
040   COM /Fld/ Ift,Istu
041   DIM Emf(20),Tw(6)
042   COM /Pr/ Qpa(20),Tfm(20),Tfmr,Ipc,Opr
043   COM /Wil/ Nrun,Itm,Iwth,Imc,Ife,Ijob,Iwd,Ifg,Ipco,Ifto,Iwil,Ihi,Ioc,Inam,H
u,Rexp,Rm
044   COM /Geom/ D1,D2,Di,Do,L,L1,L2
046   DATA 0.10086091,25727.94369,-767345.8295,78025595.81
047   DATA -9247486589,6.97688E+11,-2.66192E+13,3.94078E+14
048   READ C(*)
049   DATA 273.15,2.5943E-2,-7.2671E-7,3.2941E-11,-9.7719E-16,9.7121E-20
050   READ T55(*)
051   DATA 273.15,2.5878E-2,-5.9853E-7,-3.1242E-11,1.3275E-14,-1.0188E-18
052   READ T56(*)
053   DATA 273.15,2.5923E-2,-7.3933E-7,2.8625E-11,1.9717E-15,-2.2486E-19
```

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```
1054    READ T57(*)
1055    DATA 273.15,2.5931E-2,-7.5232E-7,4.0657E-11,-1.2791E-15,6.4402E-20
1056    READ T58(*)
1057    Dr=.015875      ! Outside diameter of the outlet end
1058    Dssp=.1524      ! Inside diameter of stainless steel test section
1059    A>=PI*Dssp^2/4
1060    Alp2=0.
1061    L=.13335        ! Condensing length
1062    L1=.060325      ! Inlet end "fin length"
1063    L2=.034925      ! Outlet end "fin length"
1064    PRINTER IS 1
1065    BEEP
1066    PRINT USING "4X,""Select option:"""
1069    PRINT USING "6X,"" 0 Take data or re-process previous data"""
1084    PRINT USING "6X,"" 1 Print raw data"""
1090    PRINT USING "6X,"" 2 WILSON Analysys"""
1093    PRINT USING "6X,"" 3 MODIFY"""
1096    PRINT USING "6X,"" 4 PURGE"""
1102    PRINT USING "6X,"" 5 RENAME"""
1105    INPUT Iso
1108    Iso=Iso+1
1111    IF Iso 1 THEN 3094
1112    BEEP
1115    INPUT "SELECT FLUID (0=WATER, 1=R-113, 2=EG)",Ift
1116    Ifto=Ift
1117    BEEP
1118    Ijob=0
1119    INPUT "ENTER INPUT MODE (0=3054A,1=FILE)",Im
1120    Im=Im+1
1123    BEEP
1124    IF Im=1 THEN
1126    INPUT "ENTER MONTH, DATE AND TIME (MM:DD:HH:MM:SS)",Date$
1129    OUTPUT 709;"TD";Date$
1132    OUTPUT 709;"TD"
1133    ENTER 709;Date$
1135    END IF
1136    IF Ijob=1 THEN
1138    BEEP
1141    INPUT "SKIP PAGE AND HIT ENTER",Ol
1144    END IF
1145    PRINTER IS 701
1146    IF Im=1 THEN
1148    ENTER 709;Date$
1150    PRINT "            Month, date and time :";Date$
1151    END IF
1153    PRINT
```

```
156    PRINT USING "10X,""NOTE: Program name : DRPOK"""
171    IF Ijob=1 THEN 1189
174    BEEP
186    INPUT "SELECT (Ci:0=FIND,1=STORED Ci)",Iwil
189    IF Im=1 THEN
192    BEEP
195    INPUT "GIVE A NAME FOR THE RAW DATA FILE",D_file$
198    PRINT USING "16X,""File name    : "",14A";D_file$
201    CREATE BDAT D_file$,30
204    ASSIGN @File TO D_file$
207    BEEP
210    INPUT "ENTER GEOMETRY CODE (1=FINNED,0=PLAIN)",Ifg
211    Inn=0
212    PRINTER IS 1
216    BEEP
217    PRINT "    ENTER INSERT TYPE:"
218    PRINT "        0=NONE (DEFAULT)"
219    PRINT "        1=TWISTED TAPE"
220    PRINT "        2=WIRE WRAP"
221    PRINT "        3=HEATEX"
222    INPUT Inn
226    OUTPUT @File;Ifg,Inn
227    Iwt=0   ! FOR UNINSTRUMENTED TUBE
228    Fh=0
231    Fp=0
234    Fw=0
235    Istu=0
237    IF Ifg=0 THEN 1241
238    INPUT "FIN PITCH, HEIGHT AND WIDTH, Fp,Fh,Fw",Fp,Fh,Fw
241    OUTPUT @File;Iwt,Fp,Fw,Fh
242    ELSE
249    BEEP
250    PRINTER IS 1
252    PRINT "  STUDENT'S DATA TO BE REPROCESSED:"
253    PRINT "  0=SWENSEN/O'KEEFE  (DEFAULT)"
254    PRINT "  1=VAN PETTEN/MITROU/COUMES/GUTTENDORF"
255    INPUT Istu
256    BEEP
257    PRINT
259    IF Istu=1 THEN
260    PRINT " STUDENT NAME:"
261    PRINT " 0=VAN PETTEN"
262    PRINT " 1=MITROU"
263    PRINT " 2=COUMES"
264    PRINT " 3=GUTTENDORF"
265    ELSE
```

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```
1267   PRINT " 4=SWENSEN"
1268   PRINT " 5=O'KEEFE"
1271   END IF
1272   INPUT Inam
1273   BEEP
1274   INPUT "GIVE THE NAME OF THE EXISTING DATA FILE",D_file$
1275   PRINTER IS 701
1276   IF Inam=0 THEN PRINT USING "16X,""Data taken by                    : VAN PETTEM
" "
1277   IF Inam=1 THEN PRINT USING "16X,""Data taken by                    : MITROU"""
1278   IF Inam=2 THEN PRINT USING "16X,""Data taken by                    : COUMES"""
1279   IF Inam=3 THEN PRINT USING "16X,""Data taken by                    : GUTTENDOFF
" "
1280   IF Inam=4 THEN PRINT USING "16X,""Data taken by                    : SWENSEN"""
1281   IF Inam=5 THEN PRINT USING "16X,""Data taken by                    : O'KEEFE"""
1282   PRINT USING "16X,""This analysis done on file : "",10A";D_file$
1283   PRINTER IS 1
1285   BEEP
1286   INPUT "ENTER NUMBER OF DATA SETS STORED",Nrun
1287   ASSIGN @File TO D_file$
1288   ENTER @File;Ifg,Inn
1289   IF Istu=0 THEN
1290   ENTER @File;Iwt,Fp,Fw,Fh
1291   ELSE
1292   IF Ifg=0 THEN ENTER @File;Iwt
1293   IF Ifg=1 THEN ENTER @File;Fp,Fw,Fh
1294   END IF
1295   END IF
1296   IF Ijob=1 THEN 1537
1297   IF Ift<0 THEN 1345
1298   BEEP
1299   PRINTER IS 1
1300   PRINT USING "4X,""Select tube type:"""
1301   PRINT USING "6X,""0 Thick wall Copper"""
1306   PRINT USING "6X,""1 Wolverine Korodense LPD Titanium Tube"""
1320   PRINT USING "6X,""2 Smooth Titanium Tube"""
1321   INPUT Iwth
1322   BEEP
1324   PRINT USING "4X,""Select tube Enhancement used:"""
1325   PRINT USING "6X,""0 SMOOTH TUBE"""
1326   PRINT USING "6X,""1 FINNED TUBE"""
1327   PRINT USING "6X,""2 WIRE-WRAPPED SMOOTH TUBE"""
1328   PRINT USING "6X,""3 LPD KORODENSE TUBE"""
1329   PRINT USING "6X,""4 WIRE-WRAPPED LPD KORODENSE TUBE"""
1330   INPUT Ityp
1331   PRINTER IS 701
```

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```
132   BEEP
133   PRINTER IS 1
134   PRINT USING "4X,""Select Material Code:"""
36    PRINT USING "6X,""0 Copper     1 Stainless steel"""
39    PRINT USING "6X,""2 Aluminum  3 90:10 Cu-Ni"""
40    PRINT USING "6X,""4 Titanium """"
42    INPUT Imc
45    PRINTER IS 1
48    BEEP
49    Itds=1
51    IF Iwth=0 THEN
52    PRINT USING "4X,""SELECT TUBE DIA TYPE:"""
57    PRINT USING "6X,""0  SMALL"""
60    PRINT USING "6X,""1  MEDIUM (DEFAULT)"""
63    PRINT USING "6X,""2  LARGE"""
66    INPUT Itds
67    END IF
69    PRINTER IS 701
72    IF Iwth=0 THEN
75    D1=.0127      ! ID OF MEDIUM AND LARGE TUBES
78    Do=.01905     ! OD OF MEDIUM TUBE
83    END IF
84    IF Iwth=1 THEN
99    D1=.01347
402   Do=.01585
405   END IF
457   IF Iwth=2 THEN
458   Do=.01585
459   D1=.01386
460   END IF
461   D1=.01905
462   D2=.01587
465   IF Itds=0 THEN
468      Do=.0127
471      D1=.009525
474   END IF
477   IF Itds=2 THEN Do=.025
478   IF Iwth=1 THEN D1=.01585
479   IF Iwth=1 THEN D2=.01585
484   IF Iwth=2 THEN D1=.01587
485   IF Iwth=2 THEN D2=.01587
487   IF Imc=0 THEN Kcu=385
489   IF Imc=1 THEN Kcu=16
492   IF Imc=2 THEN Kcu=167
495   IF Imc=3 THEN Kcu=45
496   IF Imc=4 THEN Kcu=20.1
```

```
1498  Rm=Do*LOG(Do/Di)/(2*Kcu)  ! Wall resistance based on outside area
1501  BEEP
1504  INPUT "ENTER PRESSURE CONDITION (0=V,1=A)",Ipc
1507  Ipco=Ipc
1508  Inf=0
1510  BEEP
1537  Ife=1
1538  PRINTER IS 701
1543  PRINT USING "16X,""This analysis includes end-fin effect"""
1546  PRINT USING "16X,""Thermal conductivity      = "",3D.D,"" (W/m.K)""";Kcu
1549  PRINT USING "16X,""Inside diameter, Di       = "",DD.DD,"" (mm)""";Di*100
1552  PRINT USING "16X,""Outside diameter, Do      = "",DD.DD,"" (mm)""";Do*100
1555! BEEP
1556  Ih1=0
1557  PRINTER IS 1
1558  PRINT "     SELECT INSIDE CORRELATION:"
1559  PRINT "         0=SIEDER-TATE (DEFAULT)"
1560  PRINT "         1=SLEICHER-ROUSE"
1561  PRINT "         2=PETUKHOV-POPOV"
1562  INPUT Ih1
1563  IF Ih1=0 THEN
1564  BEEP
1566  INPUT "     SELECT REYNOLDS EXPONENT",Rexp
1567  END IF
1568  Ioc=0
1569  BEEP
1570  PRINT
1571  PRINT "     SELECT OUTSIDE THEORY/CORRELATION FOR WILSON ANALYSIS:"
1572  PRINT "         0=NUSSELT THEORY (DEFAULT)"
1573  PRINT "         1=FUJII (1979) CORRELATION"
1574  INPUT Ioc
1575  BEEP
1576  Itm=1
1577  PRINT
1578  PRINT "     SELECT COOLANT TEMPERATURE RISE MEASUREMENT:"
1579  IF Istu=0 THEN PRINT "         0=SINGLE TEFLON T/C"
1580  PRINT "         1=QUARTZ THERMOMETER (DEFAULT)"
1581  PRINT "         2=10-JUNCTION THERMOPILE"
1582  INPUT Itm
1583  PRINTER IS 701
1584  IF Itm=0 THEN PRINT USING "16X,""This analysis uses the SINGLE TEFLON T/C
readings"""
1585  IF Itm=1 THEN PRINT USING "16X,""This analysis uses the QUARTZ THERMOMETE
 readings"""
1586  IF Itm=2 THEN PRINT USING "16X,""This analysis uses the 10-JUNCTION THERM
PILE readings"""
1587  I1c=1  ! FOR MODIFIED WILSON
1588  IF Ih1=0 THEN C1=.027
1589! IF Inn=2 AND Di=.009525 THEN C1=.051   !TO BE MODIFIED
1590! IF Inn=2 AND Di=.0127 THEN C1=.052
1591! IF Inn=3 THEN C1=.22
```

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192! IF Inn=0 THEN C1=.012
193! IF Ift=2 THEN C1=.035
194! END IF
195  IF Ih1=1 THEN C1=1.
196  IF Ih1=2 THEN C1=1.
197  IF Iwil=1 THEN
198  BEEP
199  INPUT "ENTER C1 IF DIFFERENT FROM STORED VALUE",C1
00   END IF
01   PRINTER IS 701
02   IF Ih1=0 THEN PRINT USING "16X,""Modified Sieder-Tate coefficient   =  ",Z
D";C1
03   IF Ih1=0 THEN PRINT USING "16X,""Chosen Reynolds No. exponent        =  ,D
D";Rexp
04   IF Ih1=1 THEN PRINT USING "16X,""Modified Sleicher-Rouse coefficient = "
,Z.4D";C1
05   IF Ih1=2 THEN PRINT USING "16X,""Modified Petukhov-Popov coefficient  = "
,Z.4D";C1
06   IF Inn=0 THEN PRINT USING "16X,""Using no insert inside tube"""
07   IF Inn=2 THEN PRINT USING "16X,""Using wire wrap insert inside tube"""
08   IF Inn=3 THEN PRINT USING "16X,""Using HEATEX insert inside tube"""
09   IF Istu=0 THEN
10   IF Inn=1 THEN PRINT USING "16X,""Using twisted tape insert inside tube"""
12   ELSE
13   IF Inn=1 THEN PRINT USING "16X,""Using wire wrap insert inside tube"""
16   END IF
17   IF Iic=0 AND Ife=1 THEN Ac=26.4
18   IF Iic=1 THEN Ac=0.
19   BEEP
20   IF Ijob=1 THEN 1648
21   PRINTER IS 1
22!  INPUT "NAME FOR A TEMPORARY PLOT FILE (TO BE PURGED)",P_file$
23   P_file$="DUMMY"
24   BEEP
34   CREATE BDAT P_file$,10
44   ASSIGN @Filep TO P_file$
48   IF Ijob=1 THEN
51   Iov=1
54   GOTO 1689
57   END IF
60   BEEP
61   INPUT "SELECT OUTPUT (0=SHORT, 1=LONG)",Iov
66   Iov=Iov+1
67   PRINTER IS 701
72   IF Ityp=0 THEN PRINT USING "16X,""Tube Enhancement   : SMOOTH TUBE"""
73   IF Ityp=1 THEN PRINT USING "16X,""Tube Enhancement   : FINNED TUBE"""
```

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```
1674   IF Ityp=2 THEN PRINT USING "16X,""Tube Enhancement   : WIRE-WRAPPED SMOOT
    TUBE"""
1675   IF Ityp=3 THEN PRINT USING "16X,""Tube Enhancement   : LPD KORODENSE TUBE
    """
1678   IF Ityp=4 THEN PRINT USING "16X,""Tube Enhancement   : WIRE-WRAPPED LPD K
RODENSE TUBE"""
1679   BEEP
1681   IF Imc=0 THEN PRINT USING "16X,""Tube material     : COPPER"""
1682   IF Imc=1 THEN PRINT USING "16X,""Tube material     : STAINLESS-STEEL"""
1683   IF Imc=2 THEN PRINT USING "16X,""Tube material     : ALUMINUM"""
1684   IF Imc=3 THEN PRINT USING "16X,""Tube material     : 90/10 CU/NI"""
1685   IF Imc=4 THEN PRINT USING "16X,""Tube material     : TITANIUM"""
1686   IF Ipc=0 THEN PRINT USING "16X,""Pressure condition : VACUUM"""
1687   IF Ipc=1 THEN PRINT USING "16X,""Pressure condition : ATMOSPHERIC"""
1688!  PRINT USING "16X,""Fin pitch, width, and height (mm): "",DD.DD,2x,Z.DD,2x
Z.DD";Fp,Fw,Fh
1689   IF (Iwil=0 OR Iwil=2) AND Im=2 THEN
1690   Ijob=1
1693   Iwd=1
1696   CALL Wilson(C1)
1699   END IF
1702   J=0
1712   IF Iov=1 THEN
1722   PRINT
1723   IF Ih1=1 THEN
1724   PRINT USING "10X,""Data   Vw       Uo        Ho        Qp       Tcf      Ts
    Reap"""
1725   PRINT USING "10X,""  #   (m/s)  (W/m^2-K)  (W/m^2-K)  (W/m^2)   (C)     (C)
(S-R)"""
1726   ELSE
1728   PRINT USING "10X,""Data    Vw        Uo          Ho          Qp        T
f    Ts"""
1729   PRINT USING "10X,""  #    (m/s)   (W/m^2-K)   (W/m^2-K)   (W/m^2)      (
)    (C)"""
1730   END IF
1740   END IF
1747   Zx=0
1750   Zx2=0
1753   Zxy=0
1756   Zy=0
1759   Sx=0
1762   Sy=0
1765   Sxs=0
1768   Sxy=0
1771   Go_on=1
1774 Repeat:!
```

```
177   J=J+1
180   IF Im=1 THEN
183   BEEP
186   INPUT "LIKE TO CHECK NG CONCENTRATION (1=Y,0=N)?",Ng
189   IF J=1 THEN
192   OUTPUT 709;"AR AF40 AL41 VR5"
195   OUTPUT 709;"AS SA"
198   END IF
801   BEEP
804   INPUT "ENTER FLOWMETER READING",Fm
807   OUTPUT 709;"AR AF60 AL62 VR5"
810   OUTPUT 709;"AS SA"
813   ENTER 709;Etp
816   OUTPUT 709;"AS SA"
819   BEEP
822   INPUT "CONNECT VOLTAGE LINE",Ok
825   ENTER 709;Bvol
828   BEEP
831   INPUT "DISCONNECT VOLTAGE LINE",Ok
834   IF Bvol<.1 THEN
837   BEEP
840   BEEP
843   INPUT "INVALID VOLTAGE - TRY AGAIN!",Ok
846   GOTO 1819
849   END IF
858   OUTPUT 709;"AS SA"
861   ENTER 709;Bamp
862   Etp=Etp*1.E+6
863   OUTPUT 709;"AR AF40 AL47 VR5"
874   Nn=7
876   FOR I=0 TO Nn
879   OUTPUT 709;"AS SA"
885   Se=0
888   FOR K=1 TO 10
891   ENTER 709;E
894   Se=Se+E
897   NEXT K
900   Emf(I)=ABS(Se/10)
916   Emf(I)=Emf(I)*1.E+6
918   NEXT I
921   OUTPUT 709;"AS SA"
924   OUTPUT 713;"T1R2E"
927   WAIT 2
930   ENTER 713;T11
933   OUTPUT 713;"T2R2E"
936   WAIT 2
```

199

```
1939   ENTER 713;T2
1942   OUTPUT 713;"T1R2E"
1945   WAIT 2
1948   ENTER 713;T12
1951   T1=(T11+T12)*.5
1954   OUTPUT 713;"T3R2E"
1960   BEEP
1970   INPUT "ENTER PRESSURE GAGE READING (Pga)",Pga
1971   Pvap1=Pga*6894.7 ! PSI TO Pa
1972   OUTPUT 709;"AR AF64 AL64 VR5"
1973   OUTPUT 709;"AS SA"    ! PRESSURE TRANSDUCER
1974   Ss=0
1975   FOR K=1 TO 20
1976   ENTER 709;Etran
1977   Ss=Ss+Etran
1978   NEXT K
1979   Ptran=ABS(Ss/20)
1980   BEEP
1981!  PRESSURE IN Pa FROM TRANSDUCER
1982   Pvap2=(-2.93604*Ptran+14.7827)*6894.7
1985   ELSE
1986   IF Istu=0 THEN
1989   ENTER @File;Bvol,Bamp,Etp,Fm,T1,T2,Pvap1,Pvap2,Emf(*)
1990   ELSE
1992   ENTER @File;Bvol,Bamp,Vtran,Etp,Emf(0),Emf(1),Emf(2),Emf(3),Emf(4),Fm,T1
2,Phg,Pwater
1994   END IF
1996   IF J=1 OR J=20 OR J=Nrun THEN
1997   Ng=1
1998   ELSE
1999   Ng=0
2000   END IF
2002   END IF
2003   IF Istu=0 THEN
2008   Tsteam1=FNTvsv57(Emf(0))
2009   Tsteam1=Tsteam1-273.15
2010   Tsteam2=FNTvsv56(Emf(1))
2011   Tsteam2=Tsteam2-273.15
2012   Tsteam=Tsteam1
2015   Troom=FNTvsv59(Emf(2))
2023   Troom=Troom-273.15
2038   Tcon=FNTvsv58(Emf(7))
2039   Tcon=Tcon-273.15
2042   ELSE
2043   Tsteam=FNTvsv(Emf(0))
2044   Troom=FNTvsv(Emf(3))
```

```
045   Tcon=FNTvsv(Emf(4))
046   END IF
048   Psat=FNPvst(Tsteam)
050   Rohg=13529-122*(Troom-26.85)/50
053   Rowater=FNRhow(Troom)
063   IF Istu=0 THEN
081   Ptest1=Pvap1
082   Ptest2=Pvap2
083   ELSE
084   Ptest2=(Phg*Rohg-Pwater*Rowater)*9.81/1000
085   END IF
087   Pks=Psat*1.E-3
088   Pkp=Ptest2*1.E-3
089   Pkt=Pks
092   Tsat=FNTvsp(Psat)
098   Vst=FNVvst(Tsteam)
104   Ppng=(Ptest2-Psat)/Ptest2
121   Ppst=1-Ppng
122   Mwv=18.016
123   IF Ift=1 THEN Mwv=137    ! TO BE CORRECTED
124   IF Ift=2 THEN Mwv=62
125   Vfng=(Ptest2-Psat)/Ptest2
126   Mfng=1/(1+(1/Vfng-1)*Mwv/28.97)
127   Mfng=Mfng*100
128   Vfng=Vfng*100
131   BEEP
134   IF Iov=2 THEN
137   PRINT
138!  RECORD TIME OF TAKING DATA
139   IF Im=1 THEN
140      OUTPUT 709;"TD"
141      ENTER 709;Told$
142   END IF
144   PRINT USING "10X,""Data set number           = "",DD,4X,14A";J,Told$
145   OUTPUT 709;"AR AF40 AL40 VR5"
146   OUTPUT 709;"AS SA"
149   END IF
152   IF Iov=2 AND Ng=1 THEN
155   PRINT USING "10X,""   Psat    Ptran    Tmeas    Tsat         NG %"""
158   PRINT USING "10X,""  (kPa)   (kPa)    (C)      (C)        Molal """
161   PRINT USING "11X,1(3D.DD,2X),1(3D.DD,3X),2(3D.DD,2X),2X,1(M3D.D,2X)";Pks,P
p,Tsteam,Tsat,Mfng
164   PRINT
167   END IF
170   IF Mfng>.5 THEN
173   BEEP
```

201

```
2176   IF Im=1 AND Ng=1 THEN
2179   BEEP
2182   PRINT
2185   PRINT USING "10X,""Energize the vacuum system """
2188   BEEP
2191   INPUT "OK TO ACCEPT THIS RUN (1=Y,0=N)?",Ol
2194   IF Ol=0 THEN
2197   BEEP
2200   DISP "NOTE: THIS DATA SET WILL BE DISCARDED!! "
2203   WAIT 5
2206   GOTO 1780
2209   END IF
2212   END IF
2215   END IF
2218   IF Im=1 THEN
2221   IF Fm<10 OR Fm>100 THEN
2224   Ifm=0
2227   BEEP
2230   INPUT "INCORRECT FM (1=ACCEPT,0=DELETE)",Ifm
2233   IF Ifm=0 THEN 1804
2236   END IF
2239   END IF
2242 ! ANALYSIS BEGINS
2243   IF Istu=0 THEN
2252   Ti1=FNTvsv58(Emf(3))
2262   Ti2=FNTvsv55(Emf(5))
2272   To1=FNTvsv58(Emf(4))
2282   To2=FNTvsv55(Emf(6))
2292   Ti1=Ti1-273.15
2302   Ti2=Ti2-273.15
2312   To1=To1-273.15
2322   To2=To2-273.15
2332   Tdel1=To1-Ti1
2342   Tdel2=To2-Ti2
2352   Tdel3=T2-T1
2353   Etp1=Emf(3)+Etp/20.
2354   Dtde=2.5931E-2-1.50464E-6*Etp1+1.21701E-10*Etp1^2-5.1164E-15*Etp1^3+3.22
E-19*Etp1^4
2355   Tris=Dtde*Etp/10.
2358   To3=Ti1+Tris
2359   IF Iov=2 THEN
2361   PRINT USING "1X,"" TIN1   TOUT1   TIN3   TOUT3   DELT1   DELT3   TFILE
"""
2362   PRINT USING "1X,""  (TEFLON)        (QUARTZ) """
2364   PRINT USING "2X,7(3D.DD,2X)";Ti1,To1,T1,T2,Tdel1,Tdel3,Tris
2365   END IF
```

202

```
267   Er1=ABS(T11-T1)
368   Er3=ABS(T12-T1)
369   PRINTER IS 1
370   BEEP
375   Er2=ABS((T2-T1)-(Tr1s))/(T2-T1)
377   IF Er2`.05 AND Im=1 THEN
378   BEEP
379   PRINT "QCT AND T-PILE DIFFER BY MORE THAN 5%"
380   Ok2=1
381   IF Ok2=0 AND Er2`.05 AND Im=1 THEN 1790
382   END IF
383   PRINTER IS 701
384   ELSE
385   T1=FNTvsv(Emf(2))
386   Grad=FNGrad((T1+T2)*.5)
387   To=T1+ABS(Etp)/(10*Grad)*1.E+6
388   T11=T1
389   To3=To
391   END IF
392   IF Istu=0 AND Itm=0 THEN
393   T1i=T11
394   T2o=To1
395   END IF
396   IF Itm=1 THEN
397   T1i=T1
398   T2o=T2
399   END IF
400   IF Itm=2 THEN
401   T1i=T11
402   T2o=To3
403   END IF
404   Tavg=(T1i+T2o)*.5
405   Ift=0
406   Cpw=FNCpw(Tavg)
407   Rhow=FNRhow(Tavg)
408   IF Istu=0 THEN
410   Md=(6.7409*Fm+13.027)/1000.
411   Md=Md*(1.0365-1.96644E-3*T1i+5.252E-6*T1i^2)/1.0037
412   ELSE
413   Md=1.04805E-2+6.80932E-3*Fm
414   Md=Md*(1.0365-1.96644E-3*T1i+5.252E-6*T1i^2)/.995434
415   END IF
417   Mf=Md/Rhow
418   Vw=Mf/(FI*D1^2/4)
419   Vws=Vw*(D1/1.27E-2)^2
421   IF Istu=0 AND Iwth=0 THEN !SWENSEN FRIC. SMOOTH COPPER TUBE
```

203

```
2422   IF Inn=0 AND Vw .5 THEN T2o=T2o-(-2.73E-4+1.75E-4*Vw+9.35E-4*Vw^2-1.96E-
Vw^3)
2423   IF Inn=1 THEN T2o=T2o-(-6.44E-5+1.71E-3*Vw+4.45E-4*Vw^2+4.07E-5*Vw^3)
2424   IF Inn=2 THEN T2o=T2o-(-3.99E-4+2.75E-3*Vw+1.45E-3*Vw^2+8.16E-5*Vw^3)
2425   IF Inn=3 THEN T2o=T2o-(8.57E-5+1.23E-3*Vw+1.08E-3*Vw^2+8.16E-5*Vw^3)
2426   END IF
2428   IF Istu=0 AND Iwth=2 THEN !FRIC FACTOR SMTH TITANIUM TUBE
2429   IF Inn=0 AND Vw^.5 THEN T2o=T2o-(-4.62E-5-7.53E-4*Vw+1.80E-3*Vw^2-8.84E-
Vw^3)
2430   IF Inn=3 THEN T2o=T2o-(2.09E-4+9.74E-4*Vw+2.12E-3*Vw^2-3.31E-5*Vw^3)
2431   END IF
2433   IF Istu=0 AND Iwth=1 THEN !FRICTION FACTORS FOR KORODENSE
2434   IF Inn=0 AND Vw>.5 THEN T2o=T2o-(-3.386E-4+1.88E-3*Vw+6.013E-4*Vw^2+4.13
-5*Vw^3)
2435   IF Inn=3 THEN T2o=T2o-(2.089E-4+9.202E-4*Vw+1.893E-3*Vw^2-2.781E-5*Vw^3)
2436   END IF
2437   IF Istu=1 THEN
2439   IF Inn=0 THEN T2o=T2o-(.0138+.001*Vw^2)
2440   IF Inn=1 THEN T2o=T2o-.004*Vws^2
2441   IF Inn=2 THEN T2o=T2o-.004*Vws^2
2444   END IF
2445   Q=Md*Cpw*(T2o-T1i)
2446   Qp=Q/(PI*Do*L)
2447   Ift=0
2448   Kw=FNKw(Tavg)
2449   Muw=FNMuw(Tavg)
2450   Rei=Rhow*Vw*Di/Muw   ! ASSUMED SAME FOR KORODENSE
2451   Prw=FNPrw(Tavg)
2452   Fe1=0.
2453   Fe2=0.
2454   Cf=1.
2455   Prwf=Prw
2456   Reif=Rei
2461   IF Ih1=0 THEN
2463   Ome=Rei^Rexp*Prw^.3333*Cf
2465   END IF
2466   IF Ih1=1 THEN
2467   Sra=.88-(.24/(4.+Prwf))
2469   Srb=.333333+.5*EXP(-.6*Prwf)
2470   Ome=(5.+.015*Reif^Sra*Prwf^Srb)
2471   END IF
2472   IF Ih1=2 THEN
2473   Eps1=(1.82*LGT(Rei)-1.64)^(-2)
2474   Ppf1=1.+3.4*Eps1
2475   Ppf2=11.7+1.8*Prw^(-1/3)
2476   Pp1=(Eps1/8)*Rei*Prw
```

```
177   Pp2=(Ppk1+Ppk2*(Eps1/8)^.5*(Prw .6666-1))
178   Ome=Pp1/Pp2
179   END IF
481   H1=kw/D1*C1*Ome
482   IF Ife=0 THEN GOTO 2491
483   P1=PI*(Do+D1)
484   A1=(D1-D1)*PI*(D1+D1)*.5
485   M1=(H1*P1/(Kcu*A1))^.5
486   P2=PI*(D1+D2)
487   A2=(D2-D1)*PI*(D1+D2)*.5
488   M2=(H1*P2/(Kcu*A2))^.5
489   Fe1=FNTanh(M1*L1)/(M1*L1)
490   Fe2=FNTanh(M2*L2)/(M2*L2)
491   Dt=Q/(PI*D1*(L+L1*Fe1+L2*Fe2)*H1)
492   IF Ih1=0 THEN
494   Cfc=(Muw/FNMuw(Tavg+Dt))^.14
495   IF ABS((Cfc-Cf)/Cfc)>.001 THEN
497   Cf=(Cf+Cfc)*.5
500   GOTO 2461
501   END IF
503   END IF
504   IF Ih1=1 THEN
505   Prwfc=FNPrw(Tavg+Dt)
506   Re1fc=Vw*D1*FNRhow(Tavg+Dt)/FNMuw(Tavg+Dt)
507   IF ABS((Prwfc-Prwf)/Prwfc)>.001 OR ABS((Re1fc-Re1f)/Re1fc)>.001 THEN
508   Prwf=(Prwfc+Prwf)/2.
509   Re1f=(Re1fc+Re1f)/2.
510   GOTO 2461
511   END IF
513   END IF
516   Ift=Ifto
517   Lmtd=(T2o-T11)/LOG((Tsteam-T11)/(Tsteam-T2o))
518   Uo=Q/(Lmtd*PI*Do*L)
519   Ho=1/(1/Uo-Do*L/(D1*(L+L1*Fe1+L2*Fe2)*H1)-Rm)
520   Tcf=Qp/Ho
521   Cpsc=FNCpw((Tcon+Tsteam)*.5)
522   Hfg=FNHfg(Tsteam)
524   Two=Tsteam-Qp/Ho
527   Tfilm=Tsteam/3+Two*2/3
530   Kf=FNKw(Tfilm)
533   Rhof=FNRhow(Tfilm)
536   Muf=FNMuw(Tfilm)
539   Hpq=.651*Kf*(Rhof^2*9.81*Hfg/(Muf*Do*Qp))^.3333
541   Hnuss=.728*(Kf^3*9.81*Hfg*Rhof^2/(Muf*Do*Tcf))^.25
542   Alp1=.728*Ho/Hnuss
548   Tfm(J-1)=Tfilm
551   Qpa(J-1)=Qp
```

```
2554   Y=Hpq*Qp .3333
2557   X=Qp
2560   Sx=Sx+X
2563   Sy=Sy+Y
2566   Sxs=Sxs+X"2
2569   Sxy=Sxy+X*Y
2572   Q1=500
2575   Qloss=Q1/(100-25)*(Tsteam-Troom)   ! TO BE MODIFIED
2578   Hfc=FNHf(Tcon)
2584   Mdv=0
2587   Bp=(Bvol*100) 2/5.76
2590   Hsc=Cpsc*(Tsteam-Tcon)
2593   Mdvc=((Bp-Qloss)-Mdv*Hsc)/Hfg
2596   IF ABS((Mdv-Mdvc)/Mdvc)>.01 THEN
2599   Mdv=(Mdv+Mdvc)*.5
2602   GOTO 2593
2605   END IF
2608   Mdv=(Mdv+Mdvc)*.5
2611   Vg=FNVvst(Tsteam)
2614   Vv=Mdv*Vg/Ax
2620   F=(9.81*Do*Muf*Hfg)/(Vv"2*Kf*(Tsteam-Two))
2623   Nu=Ho*Do/Kf
2626   Ret=Vv*Rhof*Do/Muf
2629   Nr=Nu/Ret'.5
2630   Hfuj=.96*(9.81*Hfg/Tcf)'.2*Kf'.8*Vv".1*Rhof^.5/(Do*Muf)".3
2635   IF Iov=2 THEN
2645   PRINT
2647   PRINT USING "5X,"" Vw       Re1          H1          Uo         Hfuj(DT)
   Hnu(Q)"""
2650   PRINT USING "5X,Z.DD,1X,3(MZ.3DE,1X),3X,2(MZ.3DE,3X)";Vw,Re1,H1,Uo,Hfuj,
q
2651   PRINT
2653   PRINT USING "5X,"" Vv        Ho          q          Tcf       NuRe       F
   Hnu(DT)"""
2655   PRINT USING "5X,Z.DD,1X,2(MZ.3DE,1X),2X,3D.DD,2X,3(MZ.3DE,1X)";Vv,Ho,Qp,
f,Nr,F,Hnuss
2656   PRINT
2658   END IF
2659   IF Iov=1 THEN
2660   IF Ih1=1 THEN
2661   PRINT USING "11X,DD,2X,Z.DD,1X,3(MD.3DE,1X),2(3D.DD,1X),D.DDD";J,Vw,Uo,Ho
Qp,Tcf,Tsteam,Sra
2662   ELSE
2668   PRINT USING "11X,DD,4X,Z.DD,2X,2(MD.3DE,2X),Z.3DE,3X,3D.DD,2X,3D.DD";J,Vw
Uo,Ho,Qp,Tcf,Tsteam
2671   END IF
```

```
274  END IF
275  IF Im=2 THEN
284  IF (Iwil=0 AND Ijob=1) OR Iwil 0 THEN OUTPUT @Filep;Qp,Ho
294  END IF
307  BEEP
308  IF Im=1 THEN
309  IF (Iwil=0 AND Ijob=1) OR Iwil=1 THEN OUTPUT @Filep;Qp,Ho
311  INPUT "CHANGE TCOOL RISE? 1=Y, 2=N",Itr
312  IF Itr=1 THEN GOTO 2384
313  INPUT "OK TO STORE THIS DATA SET (1=Y,0=N)?",Ols
314  IF Ols=1 THEN
325  OUTPUT @File;Bvol,Bamp,Etp,Fm,T1,T2,Pvap1,Pvap2,Emf(*)
335  Alp2=Alp1+Alp2
349  ELSE
352  J=J-1
355  END IF
358  BEEP
361  INPUT "WILL THERE BE ANOTHER RUN (1=Y,0=N)?",Go_on
364  Nrun=J
367  IF Go_on 0 THEN Repeat
370  ELSE
373  IF J Nrun THEN Repeat
376  END IF
379  IF Ijob=1 THEN 2809
382  IF Iwil=0 THEN
385  ASSIGN @File TO *
388  Ijob=1
391  Iwd=1
394  CALL Wilson(C1)
397  Im=2
400  ASSIGN @File TO D_file$
403  GOTO 1136
406  END IF
409  IF Ifg=0 THEN
412  PRINT
415  Sl=(Nrun*Sxy-Sy*Sx)/(Nrun*Sxs-Sx^2)
418  Ac=(Sy-Sl*Sx)/Nrun
422  PRINT USING "10X,""Least-Squares Line for Ho vs q curve:"""
424  PRINT USING "10X,""  Slope      = "",MD.4DE";Sl
427  PRINT USING "10X,""  Intercept  = "",MD.4DE";Ac
430  END IF
433  BEEP
443  INPUT "ENTER SAME TEMPORARY PLOT FILE NAME",Fplot$
453  ASSIGN @Filep TO P_file$
463  FOR I=1 TO Nrun
473  ENTER @Filep;Qp,Ho
```

```
2873    ENTER @Filep;Qp,Ho
2883    Xc=LOG(Qp/Ho)
2884    Yc=LOG(Qp)
2885    Zx=Zx+Xc
2886    Zx2=Zx2+Xc^2
2887    Zxy=Zxy+Xc*Yc
2888    Zy=Zy+Yc
2889    NEXT I
2890    Bb=.75
2891    Aa=EXP((Zy-Bb*Zx)/Nrun)
2892    PRINT
2893    PRINT USING "10X,""Least-squares line for q = a*delta-T^b"""
2894    PRINT USING "12X,""a = "",MZ.4DE";Aa
2895    PRINT USING "12X,""b = "",MZ.4DE";Bb
2896    IF Ift=0 THEN
2897    IF Ipc=0 THEN
2898    Qps=2.5E+5
2899    IF Iic=0 THEN Hop=9326
2902    IF Iic=1 THEN Hop=10165*(.01905/Do)^.33333
2905    END IF
2908    IF Ipc=1 THEN
2911    Qps=7.5E+5
2914    IF Iic=0 THEN Hop=7176
2917    IF Iic=1 THEN Hop=7569*(.01905/Do) .33333
2920    END IF
2923    Hos=Aa^(1/Bb)*Qps^((Bb-1)/Bb)
2926    IF Ipc=0 THEN Aas=2.32E+4
2929    IF Ipc=1 THEN Aas=2.59E+4
2930    Alpsm=.876    !SWENSEN DATA
2931    IF Iwil=0 THEN GOTO 2959
2933    Enrat=Alp2/Alpsm
2934    Enr=Hos/Hop
2935!   Enr=Aa/Aas
2938    PRINT
2941!   PRINT USING "10X,""Values computed at q = "",Z.DD,"" (MW/m^2):""";Qps/1.E
6
2944!   PRINT USING "12X,""Heat-transfer coefficient = "",DDD.DDD,"" (kW/m^2.K)""
;Hos/1000
2947    PRINT USING "12X,""Enhancement ratio (Del-T) =  "",2D.3D";Enrat
2950!   PRINT USING "10X,""Enhancement ratio at constant Delta-T  = "",DD.DD";Enr
2953!   PRINT USING "10X,""Enhancement ratio at constant q        = "",DD.DD";Enr
1.3333
2956    ELSE
2959    PRINT
2962    IF Ift=1 THEN
2965    Aas=2687.2  ! ZEBROWSKI (V = 0.4 m/s)
2968    Aas=2557.0*(.01905/Do)^.33333  ! VAN PETTEN (V = 0.25 m/s)
```

```
.368   Aas=2557.0*(.01905/Do)^.33333   ! VAN PETTEN (V = 0.25 m/s)
.371   END IF
.374   IF Ift=2 THEN Aas=9269.7*(.01905/Do)^.33333
.377   Edt=Aa/Aas
.380   Eq=Edt^(4/3)
.383!  PRINT USING "10X,""Enhancement (q)     = "",DD.3D";Eq
.386!  PRINT USING "10X,""Enhancement (Del-T) = "",DD.3D";Edt
.389   END IF
.392!  IF Im=1 THEN
.395   BEEP
.398   PRINT
.001   PRINT USING "10X,""NOTE: "",ZZ,"" data points were stored in file "",10A";
  ,D_file$
.004!  END IF
.007   BEEP
.013   PRINT
.016   PRINT USING "10X,""NOTE: "",ZZ,"" X-Y pairs were stored in data file "",10
.";J,Plot$
.031   BEEP
.073   ASSIGN @File TO *
.079   ASSIGN @Filep TO *
.080   PURGE "DUMMY"
.094   IF Iso=2 THEN CALL Raw
.100   IF Iso=3 THEN CALL Wilson(Ci)
.103   IF Iso=4 THEN CALL Modify
.106   IF Iso=5 THEN CALL Purg
.112   IF Iso=6 THEN CALL Renam
.116   END
.118   DEF FNPvst(Tc)
.121   COM /Fld/ Ift,Istu
.124   DIM K(8)
.127   IF Ift=0 THEN
.130   DATA -7.691234564,-26.08023696,-168.1706546,64.23285504,-118.9646225
.133   DATA 4.16711732,20.9750676,1.E9,6
.136   READ K(*)
.139   T=(Tc+273.15)/647.3
.142   Sum=0
.145   FOR N=0 TO 4
.148   Sum=Sum+K(N)*(1-T)^(N+1)
.151   NEXT N
.154   Br=Sum/(T*(1+K(5)*(1-T)+K(6)*(1-T)^2))-(1-T)/(K(7)*(1-T)^2+K(8))
.157   Pr=EXP(Br)
.160   P=22120000*Pr
.163   END IF
.165   IF Ift=1 THEN
.169   Tf=Tc*1.8+32+459.6
.172   P=10^(33.0655-4330.98/Tf-9.2635*LGT(Tf)+2.0539E-3*Tf)
```

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```
3175  P=P*101325/14.696
3178  END IF
3181  IF Ift=2 THEN
3184  A=9.394685-3066.1/(Tc+273.15)
3187  P=133.32*10^A
3190  END IF
3193  RETURN P
3196  FNEND
3199  DEF FNHfg(T)
3202  COM /Fld/ Ift,Istu
3205  IF Ift=0 THEN
3208  Hfg=2477200-2450*(T-10)
3211  END IF
3214  IF Ift=1 THEN
3217  Tf=T*1.8+32
3220  Hfg=7.0557857E+1-Tf*(4.838052E-2+1.2619048E-4*Tf)
3223  Hfg=Hfg*2326
3226  END IF
3229  IF Ift=2 THEN
3232  Tk=T+273.15
3235  Hfg=1.35264E+6-Tk*(6.38263E+2+Tk*.747462)
3238  END IF
3241  RETURN Hfg
3244  FNEND
3247  DEF FNMuw(T)
3250  COM /Fld/ Ift,Istu
3253  IF Ift=0 THEN
3256  A=247.8/(T+133.15)
3259  Mu=2.4E-5*10^A
3262  END IF
3265  IF Ift=1 THEN
3268  Mu=8.9629819E-4-T*(1.1094609E-5-T*5.566829E-8)
3271  END IF
3274  IF Ift=2 THEN
3277  Tk=1/(T+273.15)
3280  Mu=EXP(-11.0179+Tk*(1.744E+3-Tk*(2.80335E+5-Tk*1.12661E+8)))
3283  END IF
3286  RETURN Mu
3289  FNEND
3292  DEF FNVvst(Tt)
3295  COM /Fld/ Ift,Istu
3298  IF Ift=0 THEN
3301  P=FNPvst(Tt)
3304  T=Tt+273.15
3307  X=1500/T
3310  F1=1/(1+T*1.E-4)
```

```
313    F2=(1-EXP(-X))^2.5*ExP(X)/X^.5
316    B=.0015*F1-.000942*F2-.0004882*X
319    k=2*P/(461.52*T)
322    V=(1+(1+2*B*k)^.5)/k
325    END IF
328    IF Ift=1 THEN
331    Tf=Tt*1.8+32
334    V=13.955357-Tf*(.16127262-Tf*5.1726190E-4)
337    V=V/16.018
340    END IF
343    IF Ift=2 THEN
346    Tk=Tt+273.15
349    P=FNPvst(Tt)
352    V=133.95*Tk/P
355    END IF
358    RETURN V
361    FNEND
364    DEF FNCpw(T)
367    COM /Fld/ Ift,Istu
370    IF Ift=0 THEN
373    Cpw=4.21120858-T*(2.26826E-3-T*(4.42361E-5+2.71428E-7*T))
376    END IF
379    IF Ift=1 THEN
382    Cpw=9.2507273E-1+T*(9.3400433E-4+1.7207792E-6*T)
385    END IF
388    IF Ift=2 THEN
391    Tk=T+273.15
394    Cpw=4.1868*(1.6894E-2+Tk*(3.35083E-3-Tk*(7.224E-6-Tk*7.61748E-9)))
397    END IF
400    RETURN Cpw*1000
403    FNEND
406    DEF FNRhow(T)
409    COM /Fld/ Ift,Istu
412    IF Ift=0 THEN
415    Ro=999.52946+T*(.01269-T*(5.482513E-3-T*1.234147E-5))
418    END IF
421    IF Ift=1 THEN
424    Ro=1.6207479E+3-T*(2.2186346+T*2.3578291E-3)
427    END IF
430    IF Ift=2 THEN
433    Tk=T+273.15-338.15
436    Vf=9.24848E-4+Tk*(6.2796E-7+Tk*(9.2444E-10+Tk*3.057E-12))
439    Ro=1/Vf
442    END IF
445    RETURN Ro
448    FNEND
```

```
3451   DEF FNPrw(T)
3454   Prw=FNCpw(T)*FNMuw(T)/FNKw(T)
3457   RETURN Prw
3460   FNEND
3463   DEF FNKw(T)
3466   COM /Fld/ Ift,Istu
3469   IF Ift=0 THEN
3472   X=(T+273.15)/273.15
3475   Kw=-.92247+X*(2.8395-X*(1.8007-X*(.52577-.07344*X)))
3478   END IF
3481   IF Ift=1 THEN
3484   Kw=8.2095238E-2-T*(2.2214286E-4+T*2.3809524E-8)
3487   END IF
3490   IF Ift=2 THEN
3493   Tk=T+273.15
3496   Kw=4.1868E-4*(519.442+.320920*Tk)
3499   END IF
3502   RETURN Kw
3505   FNEND
3508   DEF FNTanh(X)
3511   P=EXP(X)
3514   Q=EXP(-X)
3517   Tanh=(P-Q)/(P+Q)
3520   RETURN Tanh
3523   FNEND
3526   DEF FNTvsv(V)
3529   COM /Cc/ C(7)
3532   T=C(0)
3535   FOR I=1 TO 7
3538   T=T+C(I)*V^I
3541   NEXT I
3544'  T=T+4.73386E-3+T*(7.692834E-3-T*8.077927E-5)
3547   RETURN T
3550   FNEND
3553   DEF FNHf(T)
3556   COM /Fld/ Ift,Istu
3559   IF Ift=0 THEN
3562   Hf=T*(4.203849-T*(5.88132E-4-T*4.55160317E-6))
3565   END IF
3568   IF Ift=1 THEN
3571   Tf=T*1.8+32
3574   Hf=8.2078571+Tf*(.19467857+Tf*1.3214286E-4)
3577   Hf=Hf*2.326
3580   END IF
3583   IF Ift=2 THEN
3586   Hf=250   ! TO BE VERIFIED
```

```
689    END IF
692    RETURN Hf*1000
695    FNEND
698    DEF FNGrad(T)
601    Grad=37.9853+.104388*T
604    RETURN Grad
607    FNEND
610    DEF FNTvsp(P)
613    Tu=190
616    Tl=10
619    Ta=(Tu+Tl)*.5
622    Pc=FNPvst(Ta)
625    IF ABS((P-Pc)/P).0001 THEN
628    IF Pc<P THEN Tl=Ta
631    IF Pc P THEN Tu=Ta
634    GOTO 3619
637    END IF
640    RETURN Ta
643    FNEND
646    DEF FNSigma(T)
649    X=647.3-T-273.15
652    S=.1160936807/(1+.83*X)+1.121404688E-3-5.75280518E-6*X+1.28627465E-8*X^2-1
14971929E-11*X^3
655    RETURN S*.001*X^2
658    FNEND
661    SUB Raw
662    COM /Fld/ Ift,Istu
664    DIM X(28)
670    INPUT "ENTER TUBE NUMBER",Itn
676    INPUT "ENTER FILE NAME",File$
679    ASSIGN @File TO File$
680    INPUT "STUDENT (0=Swensen)",Istu
681    INPUT "SMOOTH OR FINNED (0=SMOOTH, 1=FINNED)",Ifg
683    INPUT "ENTER TUBE SIZE (0=S,1=M,2=L,3=OMC)",Itds
685    INPUT "ENTER PRESSURE CONDITION (0=V,1=A)",Ipc
688    IF Ipc=0 AND Ift=0 THEN Vs=2
691    IF Ipc=0 AND Ift=2 THEN Vs=10
692    IF Ipc=1 AND Ift=0 THEN Vs=1
693    IF Ipc=1 AND Ift=1 THEN Vs=.25
694    IF Istu=1 THEN Vs=2
696    Nrun=18
700    INPUT "ENTER NUMBER OF RUNS",Nrun
703    PRINTER IS 701
706    PRINT
709    PRINT
710    IF Istu=0 THEN PRINT USING "10x,""Data of Swensen"""
```

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```
6715    IF Ift=0 THEN PRINT USING "10X,""Vapor is steam"""
6716    IF Ift=1 THEN PRINT USING "10X,""Vapor is R-113"""
6717    IF Ift=2 THEN PRINT USING "10X,""Vapor is ethylene glycol"""
6719    IF Itds=0 THEN PRINT USING "10X,""Tube diameter:    Small"""
6720    IF Itds=1 THEN PRINT USING "10X,""Tube diameter:    Medium"""
6721    IF Itds=2 THEN PRINT USING "10X,""Tube diameter:    Large"""
6722    IF Itds=3 THEN PRINT USING "10X,""Tube diameter:    QMC"""
6724    PRINT
6725    PRINT USING "10X,""Tube Number:         "",ZZ";Itn
6726    PRINT USING "10X,""File Name:           "",14A";File$
6727    IF Ifg=0 THEN PRINT USING "10X,""Tube Type:   Smooth"""
6728    IF Ifg=1 THEN PRINT USING "10X,""Tube Type:   Finned"""
6730    IF Ipc=0 THEN
6731    PRINT USING "10X,""Pressure Condition: Vacuum"""
6732    ELSE
6733    PRINT USING "10X,""Pressure Condition: Atmospheric"""
6734    END IF
6735!   PRINT USING "10X,""Vapor Velocity:     "",DD.DD,"" (m/s)""";Vs
6736    ENTER @File;Ifg,Inn
6739    IF Itds=1 OR Itds=2 THEN D1=.0127
6742    IF Itds=0 OR Itds=3 THEN D1=.009525
6747    ENTER @File;Iwt,Fp,Fw,Fh
6748    IF Istu=0 AND Ifg=1 THEN
6750    Fp=Fp-1
6751    PRINT USING "10X,""Fin spacing, width and height (mm): "",DD.DD,2X,Z.DD,
        ,Z.DD";Fp,Fw,Fh
6752    END IF
6756    PRINT
6757    PRINT USING "10X,""Data    Vw      Tin     Tout      Ts"""
6758    PRINT USING "10X,"" #     (m/s)    (C)     (C)      (C)"""
6760    PRINT
6763    FOR I=1 TO Nrun
6766    ENTER @File;X(*)
6769    Ts=FNTvsv57((X(8)+X(9))/2.)
6770    Ts=Ts-273.15
6772    Fm=X(3)
6775    T1=X(4)
6778    T2=X(5)
6781    Tavg=(T1+T2)*.5
6784    Ift=0
6785    Rhow=FNRhow(Tavg)
6787    Md=(6.7409*Fm+13.027)/1000.
6790    Md=Md*(1.0365-1.96644E-3*T1+5.252E-6*T1^2)/1.0037
6793    Mf=Md/Rhow
6796    Vw=Mf/(PI*D1^2/4)
6799    IF Inn=0 AND Vw .5 THEN T2=T2-(-2.73E-4+1.75E-4*Vw+9.35E-4*Vw^2-1.96E-5*V
        ^3)
```

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```
809    IF Inn=1 THEN T2=T2-(-6.44E-5+1.71E-3*Vw+4.45E-4*Vw^2+4.07E-5*Vw^3)
810    IF Inn=2 THEN T2=T2-(-3.99E-4+2.75E-3*Vw+1.45E-3*Vw^2+8.16E-5*Vw^3)
811    IF Inn=3 THEN T2=T2-(8.57E-5+1.23E-3*Vw+1.08E-3*Vw^2+8.16E-5*Vw^3)
814    PRINT USING "10X,DD,5X,D.DD,3X,2(DD.DD,3X),DDD.DD";I,Vw,T1,T2,Ts
817    NEXT I
820    ASSIGN @File TO *
823    SUBEND
826    SUB Wilson(C1)
829    COM /Wil/ Nrun,Itm,Iwth,Imc,Ife,Ijob,Iwd,Ifg,Ipco,Ifto,Iwil,Ih1,Ioc,Inam,P
u,Rexp,Rm
832    COM /Fld/ Ift,Istu
833    COM /Geom/ D1,D2,Di,Do,L,L1,L2
835    DIM Emf(20),Bvo(25),Bam(25),Eata(25),Ear(25,7),Fma(25),T1a(25),T2a(25)
845    IF Ioc=0 THEN
847    PRINT USING "16X,""Nusselt theory is used for Ho"""
848    ELSE
849    PRINT USING "16X,""Fujii correlation used for Ho"""
850    END IF
853    BEEP
856    INPUT "RE-ENTER DATA FILE BEING PROCESSED",D_file$
859    BEEP
862    INPUT "GIVE A NAME FOR XY PLOT-DATA FILE",Plot$
865    CREATE BDAT Plot$,10
868    ASSIGN @Io_path TO Plot$
871    Jj=0
874    ASSIGN @File TO D_file$
877    ENTER @File;Ifg,Inn
878    IF Istu=0 THEN
883    ENTER @File;Ddd,Ddd,Ddd,Ddd
884    ELSE
885    IF Ifg=0 THEN ENTER @File;Iwt
886    IF Ifg=1 THEN ENTER @File;Fp,Fw,Fh
887    END IF
888    IF Jj=0 THEN
895    IF Ih1=0 THEN C1=.027
896    IF Ih1=1 THEN C1=1.00
897    IF Ih1=2 THEN C1=1.00
899    IF Ifg=0 THEN Alp=1.2
900    IF Ifg=1 THEN Alp=2.6
901    IF Ift=2 AND Ifg=1 THEN Alp=5.0
904    END IF
907    J=0
910    Sx=0
913    Sy=0
916    Sxs=0
919    Sxy=0
```

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```
6922! READ DATA FROM A USER-SPECIFIED FILE IF INPUT MODE (Im) = 2
6925    IF Jj=0 THEN
6926    IF Istu=0 THEN
6931    ENTER @File;Bvol,Bamp,Etp,Fm,T1,T2,Ddd,Ddd,Emf(*)
6932    ELSE
6934    ENTER @File;Bvol,Bamp,Vtran,Etp,Emf(0),Emf(1),Emf(2),Emf(3),Emf(4),Fm,T1
2,Phg,Pwater
6936    END IF
6938    Bvo(J)=Bvol
6939    Bam(J)=Bamp
6940    Eata(J)=Etp
6943    Ear(J,0)=Emf(0)
6946    Ear(J,1)=Emf(1)
6949    Ear(J,2)=Emf(2)
6952    Ear(J,3)=Emf(3)
6955    Ear(J,4)=Emf(4)
6956    IF Istu=1 THEN GOTO 6961
6958    Ear(J,5)=Emf(5)
6959    Ear(J,6)=Emf(6)
6960    Ear(J,7)=Emf(7)
6961    Fma(J)=Fm
6962    T1a(J)=T1
6964    T2a(J)=T2
6967    ELSE
6970    Bvol=Bvo(J)
6973    Bamm=Bam(J)
6976    Etp=Eata(J)
6979    Emf(0)=Ear(J,0)
6982    Emf(1)=Ear(J,1)
6985    Emf(2)=Ear(J,2)
6988    Emf(3)=Ear(J,3)
6991    Emf(4)=Ear(J,4)
6992    IF Istu=1 THEN GOTO 6997
6994    Emf(5)=Ear(J,5)
6995    Emf(6)=Ear(J,6)
6996    Emf(7)=Ear(J,7)
6997    Fm=Fma(J)
6998    T1=T1a(J)
7000    T2=T2a(J)
7003    END IF
7004    IF Istu=0 THEN
7006    Tsat=FNTvsv57((Emf(0)+Emf(1))/2.)
7007    Tsat=Tsat-273.15
7009    Ti=FNTvsv58(Emf(3))
7010    To1=FNTvsv58(Emf(4))
7012    T1=T1-273.15
```

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```
)13    To1=To1-273.15
)15    Etp1=Emf(3)+Etp/20.
)16    Dtde=2.5931E-2-1.50464E-6*Etp1+1.21701E-10*Etp1 2-5.1164E-15*Etp1 3+3.220
-19*Etp1 4
)17    Tris=Dtde*Etp/10.
)18    To=T1+Tris
)19    ELSE
)20    Tsat=FNTvsv(Emf(0))
)21    T1=FNTvsv(Emf(2))
)22    Grad=FNGrad((T1+T2)*.5)
)23    To=T1+ABS(Etp)/(10*Grad)*1.E+6
)24    END IF
)25!   CALCULATE THE LOG-MEAN-TEMPERATURE DIFFERENCE
)26    IF Istu=0 AND Itm=0 THEN
)27    Tf=T1
028    Tl=To1
029    END IF
030    IF Itm=1 THEN
031    Tf=T1
032    Tl=T2
033    END IF
034    IF Itm=2 THEN
035    Tf=T1
036    Tl=To
038    END IF
039    Tavg=(Tf+Tl)*.5
040    Trise=Tl-Tf
041    Lmtd=Trise/LOG((Tsat-Tf)/(Tsat-Tl))
042    Ift=0
043    Cpw=FNCpw(Tavg)
044    Rhow=FNRhow(Tavg)
045    Kw=FNKw(Tavg)
048    Muwa=FNMuw(Tavg)
051    Prw=FNPrw(Tavg)
054    Ift=Ifto
055    IF Istu=0 THEN
057    Mdt=(6.7409*Fm+13.027)/1000.
060    Md=Mdt*(1.0365-Tf*(1.96644E-3-Tf*5.252E-6))/1.0037
061    ELSE
062    Mdt=1.04805E-2+6.80932E-3*Fm
063    Md=Mdt*(1.0365-Tf*(1.96644E-3-Tf*5.252E-6))/.995434
065    END IF
066    Vf=Md/Rhow
067    Vw=Vf/(PI*D1 2/4)
068    Vws=Vw*(D1/1.27E-2)^2
070    IF Istu=0 AND Iwth=0 THEN !SWENSEN FRICTION FAC. FOR COPPER TUBE
```

```
7075   IF Inn=0 AND Vw .5 THEN Trise=Trise-(-2.73E-4+1.75E-4*Vw+9.35E-4*Vw 2-1.9
E-5*Vw 3)
7078   IF Inn=1 THEN Trise=Trise-(-6.44E-5+1.71E-3*Vw+4.45E-4*Vw^2+4.07E-5*Vw 3
7079   IF Inn=2 THEN Trise=Trise-(-3.99E-4+2.75E-3*Vw+1.45E-3*Vw^2+8.16E-5*Vw 3.
7080   IF Inn=3 THEN Trise=Trise-(8.57E-5+1.23E-3*Vw+1.08E-3*Vw^2+8.16E-5*Vw 3)
7081   END IF
7083   IF Istu=0 AND Iwth=2 THEN !OKEEFE FRIC. FAC. FOR SMOOTH TITANIUM TUBE.
7085   IF Inn=0 AND Vw .5 THEN Trise=Trise-(-4.62E-5-7.53E-4*Vw+1.80E-3*Vw 2-6.8
E-5*Vw 3)
7086   IF Inn=3 THEN Trise=Trise-(2.09E-4+9.74E-4*Vw+2.12E-3*Vw^2-3.31E-5*Vw 3)
7087   END IF
7088   IF Istu=0 AND Iwth=1 THEN !FRICTION FACTORS FOR KORODENSE
7089   IF Inn=0 AND Vw>.5 THEN Trise=Trise-(-3.386E-4+1.88E-3*Vw+6.013E-4*Vw 2+4
133E-5*Vw^3)
7090   IF Inn=3 THEN Trise=Trise-(2.089E-4+9.202E-4*Vw+1.893E-3*Vw 2-2.781E-5*Vw
3)
7091   END IF
7092   IF Istu=1 THEN
7093   IF Inn=0 THEN Trise=Trise-(.0138+.001*Vw 2)
7094   IF Inn=1 THEN Trise=Trise-.004*Vws^2
7095   IF Inn=2 THEN Trise=Trise-.004*Vws^2
7100   END IF
7108   Q=Md*Cpw*Trise
7111   Qp=Q/(PI*Do*L)
7114   Uo=Qp/Lmtd
7117   Re=Rhow*Vw*Di/Muwa
7120   Fe1=0
7123   Fe2=0
7126   Cf=1.
7127   Prwf=Prw
7128   Reif=Re
7129   Ift=0
7131   Two=Tsat-5
7132   Tfilm=Tsat/3+Two*2/3
7135   Kf=FNKw(Tfilm)
7138   Rhof=FNRhow(Tfilm)
7141   Muf=FNMuw(Tfilm)
7144   Hfgp=FNHfg(Tsat)+.68*FNCpw(Tfilm)*(Tsat-Two)
7147!  New=Kf*(Rhof 2*9.81*Hfgp/(Muf*Do*Qp)) .3333
7148   New=(Kf 3*9.81*Hfgp*Rhof 2/(Muf*Do*(Tsat-Two))) .25
7150   IF Ioc=1 THEN
7153!  New=Kf*((9.81*Hfgp/Qp)^.25)*((Muf*Do)^(-.375))*(Rhof .625 *(Vv .125)
7154   New=(9.81*Hfgp/(Tsat-Two)) .2*Kf^.8*Vv .1*Rhof .5/(Do*Muf)^.3
7156   END IF
7159   Ho=Alp*New
7162   Twoc=Tsat-Qp/Ho
```

```
165    IF ABS((Twoc-Two)/Twoc) .001 THEN
168    Two=Twoc
171    GOTO 7132
174    END IF
175    Rexp1=Rexp
184    IF Ih1=0 THEN
185    Omega=Re Rexp1*Prw".3333*Cf
187    END IF
188    IF Ih1=1 THEN
189    Sra=.88-(.24/(4.+Prwf))
190    Srb=.333333+.5*EXP(-6*Prwf)
191    Omega=(5.+.015*Re1f^Sra*Prwf Srb)
192    END IF
193    IF Ih1=2 THEN
194    Eps1=(1.82*LGT(Re)-1.64)"(-2)
195    Ppk1=1.+3.4*Eps1
196    Ppk2=11.7+1.8*Prw"(-1/3)
197    Pp1=(Eps1/8)*Re*Prw
198    Pp2=(Ppk1+Ppk2*(Eps1/8)".5*(Prw".6666-1))
199    Omega=Pp1/Pp2
200    END IF
202    H1=Kw/D1*C1*Omega
203    IF Ife=0 THEN 7216
204    P1=PI*(D1+D1)
205    P2=PI*(D1+D2)
206    A1=(D1-D1)*PI*(D1+D1)*.5
207    A2=(D2-D1)*PI*(D1+D2)*.5
208    M1=(H1*P1/(Kcu*A1))'.5
209    M2=(H1*P2/(Kcu*A2))'.5
210    Fe1=FNTanh(M1*L1)/(M1*L1)
213    Fe2=FNTanh(M2*L2)/(M2*L2)
216    Dt=Q/(PI*D1*(L+L1*Fe1+L2*Fe2)*H1)
217    IF Ih1=0 THEN
219    Muw1=FNMuw(Tavg+Dt)
222    Cfc=(Muwa/Muw1)".14
225    IF ABS((Cfc-Cf)/Cfc) .001 THEN
228    Cf=(Cf+Cfc)*.5
231    GOTO 7184
232    END IF
234    END IF
235    IF Ih1=1 THEN
236    Prwfc=FNPrw(Tavg+Dt)
237    Re1fc=Vw*D1*FNRhow(Tavg+Dt)/FNMuw(Tavg+Dt)
239    IF ABS((Prwfc-Prwf)/Prwfc) .001 OR ABS((Re1fc-Re1f)/Re1fc) .001 THEN
240    Prwf=(Prwfc+Prwf)/2.
241    Re1f=(Re1fc+Re1f)/2.
```

```
7242    GOTO 7184
7243    END IF
7245    END IF
7246    Ift=Ifto
7247    X=Do*New*L/(Omega*kw*(L+L1*Fe1+L2*Fe2))
7248    Y=New*(1/Uo-Rm)
7249!   COMPUTE COEFFICIENTS FOR THE LEAST-SQUARES-FIT STRAIGHT LINE
7250    IF Jp=1 THEN OUTPUT @Io_path;X,Y
7252    Sx=Sx+X
7255    Sy=Sy+Y
7258    Sxs=Sxs+X*X
7261    Sxy=Sxy+X*Y
7264    IF Im=1 AND Jj=0 THEN OUTPUT @File;Bvol,Bamp,Etp,Fm,T1,T2,Pvap1,Pvap2,Em
*)
7267    J=J+1
7270    IF J<Nrun THEN 6925
7273    S1=(Nrun*Sxy-Sy*Sx)/(Nrun*Sxs-Sx^2)
7276    IF Iwil=2 THEN
7279!       IF Inn=1 AND D1=.009525 THEN S1=1/.051   !TO BE MODIFIED
7282!       IF Inn=0 THEN S1=1/.012
7283!       IF Inn=3 THEN S1=1/.22
7285!       IF Inn=1 AND D1=.0127 THEN S1=1/.052
7286!       IF Ift=2 THEN S1=1/.035
7287    IF Ih1=0 THEN S1=1/.027
7288    IF Ih1=1 THEN S1=1/1.00
7289    IF Ih1=2 THEN S1=1/1.00
7291    END IF
7294    Ac=(Sy-S1*Sx)/Nrun
7297    C1c=1/S1
7300    Alpc=1/Ac
7303    Jj=Jj+1
7306    IF Jp=1 THEN Jp=2
7309    Cerr=ABS((C1c-C1)/C1c)
7312    Aerr=ABS((Alpc-Alp)/Alpc)
7315    IF Cerr>.001 OR Aerr .001 THEN
7318    C1=(C1c+C1)*.5
7321    Alp=(Alpc+Alp)*.5
7324    BEEP
7327    IF Ijob=1 THEN 6907
7330    ELSE
7333    IF Jp=0 THEN Jp=1
7336    END IF
7339    IF Jp=1 THEN 6874
7342    C1=(C1+C1c)*.5
7345    PRINT
7346    IF Ih1=0 THEN
```

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```
348    PRINT USING "10X,""C₁ (based on Sieder-Tate)       =    "",Z.4D";C₁
349    END IF
350    IF Ih₁=1 THEN
351    PRINT USING "10X,""C₁ (based on Sleicher-Rouse)    =    "",Z.4D";C₁
352'   PRINT USING "10X,""Re exponent for Sleicher-Rouse  =    "",D.DDD";Sra
353    END IF
354    IF Ih₁=2 THEN
355    PRINT USING "10X,""C₁ (based on Petulhov-Popov)     =    "",Z.4D";C₁
356    END IF
357    IF Ioc=0 THEN
358    PRINT USING "10X,""Alpha (based on Nusselt (Tdel)) =    "",Z.4D";Alp
359    END IF
360    IF Ioc=1 THEN
361    PRINT USING "10X,""Alpha (based on Fujii (Tdel))   =    "",Z.4D";Alp
362    END IF
363    IF Inam=5 THEN
364    IF Ih₁=0 THEN
366    IF Ipco=0 AND Inn=0 THEN Alpsm=.8218    !NO INSERT,VACUUM,S-T
367    IF Ipco=1 AND Inn=0 THEN Alpsm=.7793    !NO INSERT,ATMOSPHERIC,S-T
368    IF Ipco=0 AND Inn=3 THEN Alpsm=.7854    !HEATEX,VACUUM,S-T
369    IF Ipco=1 AND Inn=3 THEN Alpsm=.7769    !HEATEX,ATMOSPHERIC,S-T
371    END IF
372    IF Ih₁=1 THEN
373    IF Ipco=0 AND Inn=0 THEN Alpsm=.8613    !NO INSERT,VACUUM,S-R
374    IF Ipco=1 AND Inn=0 THEN Alpsm=.8218    !NO INSERT,ATMOSPHERIC,S-R
375    IF Ipco=0 AND Inn=3 THEN Alpsm=.7791    !HEATEX,VACUUM,S-R
376    IF Ipco=1 AND Inn=3 THEN Alpsm=.7929    !HEATEX,ATMOSPHERIC,S-R
378    END IF
379    IF Ih₁=2 THEN
380    IF Ipco=0 AND Inn=0 THEN Alpsm=.8205    !NO INSERT,VACUUM,P-P
381    IF Ipco=1 AND Inn=0 THEN Alpsm=.7654    !NO INSERT,ATMOSPHERIC,P-P
382    IF Ipco=0 AND Inn=3 THEN Alpsm=.7670    !HEATEX,VACUUM,P-P
383    IF Ipco=1 AND Inn=3 THEN Alpsm=.7708    !HEATEX,ATMOSPHERIC,P-P
385    END IF
386    END IF
387    IF Inam=4 THEN
390    IF Ipco=1 THEN Alpsm=.876    !SWENSEN DATA BASED ON DEL-T
391    END IF
392    IF Inam=0 OR Inam=3 THEN
393    IF Ipco=0 THEN Alpsm=.83    !VP M1STV103
394    IF Ipco=1 THEN Alpsm=.88    !VP SMTHSTA65
396'   IF Ift=1 THEN Alpsm=.733    !ZEBROWSKI (V = 0.45 m/s)
397    IF Ift=1 THEN Alpsm=.677    !VAN PETTEN (V = 0.25 m/s)
398    IF Ift=2 THEN Alpsm=1.262
399    END IF
401    IF Inam=1 THEN   !MITROU ALPHA FOR P-P FROM REPROCESSING
```

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```
7402  IF Ipco=0 THEN Alpsm=.8437
7403  IF Ipco=1 THEN Alpsm=.8418
7404  END IF
7405  Et=Alp/Alpsm
7406  Eq=Et^1.333333
7407  PRINT USING "10X,""Enhancement (q)                       = "",DD.3D";Eq
7408  PRINT USING "10X,""Enhancement (Del-T)                   = "",DD.3D";Et
7409  ASSIGN @File TO *
7410  SUBEND
7519  SUB Modify
7520  COM /Fld/ Ift,Istu
7522  DIM Emf(20)
7525  BEEP
7528  INPUT "ENTER NAME OF FILE TO BE MODIFIED",Fileo$
7531  ASSIGN @Fileo TO Fileo$
7534  CREATE BDAT "TEST",30
7537  ASSIGN @Filed TO "TEST"
7540  ENTER @Fileo;Ifg,Inn
7543  OUTPUT @Filed;Ifg,Inn
7544  IF Istu=0 THEN
7546  ENTER @Fileo;Iwt,Fp,Fw,Fh
7547  OUTPUT @Filed;Iwt,Fp,Fw,Fh
7548  ELSE
7549  IF Ifg=0 THEN
7551  ENTER @Fileo;Iwt
7552  OUTPUT @Filed;Iwt
7553  END IF
7554  IF Ifg=1 THEN
7555  ENTER @Fileo;Fp,Fw,Fh
7556  OUTPUT @Filed;Fp,Fw,Fh
7557  END IF
7559  END IF
7560  BEEP
7561  INPUT "ENTER NUMBER OF DATA SETS STORED",N
7562  FOR I=1 TO N
7563  IF Istu=0 THEN
7565  ENTER @Fileo;Bvol,Bamp,Etp,Fm,T1,T2,Pvap1,Pvap2,Emf(*)
7566  ELSE
7567  ENTER @Fileo;Bvol,Bamp,Vtran,Etp,Emf(0),Emf(1),Emf(2),Emf(3),Emf(4),Fm,T
T2,Phg,Pwater
7568  END IF
7570'    PERFORM CORRECTIONS
7571  PRINT USING "2X,""DO YOU WISH TO DELETE POINT"",DD,""?""";I
7572  INPUT "0=YES, 1=NO",Idel
7573  IF Idel=0 THEN 7580
7576  IF Istu=0 THEN
```

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```
577    OUTPUT @Filed;Bvol,Bamp,Etp,Fm,T1,T2,Pvap1,Pvap2,Emf(*)
578    ELSE
579    OUTPUT @Filed;Bvol,Bamp,Vtran,Etp,Emf(0),Emf(1),Emf(2),Emf(3),Emf(4),Fm,T1
T2,Phg,Pwater
580    END IF
581    NEXT I
582    ASSIGN @Fileo TO *
583    ASSIGN @Filed TO *
584    SUBEND
585    SUB Purg
588    BEEP
591    INPUT "ENTER FILE NAME TO BE DELETED",File$
594    PURGE File$
597    GOTO 7588
600    SUBEND
690    SUB Renam
693    BEEP
696    INPUT "ENTER FILE NAME TO BE RENAMED",File1$
699    BEEP
702    INPUT "ENTER NEW NAME FOR FILE",File2$
705    RENAME File1$ TO File2$
708    GOTO 7693
711    SUBEND
721    DEF FNTvsv55(V)
731    COM /Cc55/ T55(5)
741    T=T55(0)
751    FOR I=1 TO 5
761    T=T+T55(I)*V^I
771    NEXT I
781    RETURN T
791    FNEND
801    DEF FNTvsv56(V)
811    COM /Cc56/ T56(5)
821    T=T56(0)
831    FOR I=1 TO 5
841    T=T+T56(I)*V^I
851    NEXT I
861    RETURN T
871    FNEND
881    DEF FNTvsv57(V)
891    COM /Cc57/ T57(5)
901    T=T57(0)
911    FOR I=1 TO 5
921    T=T+T57(I)*V^I
931    NEXT I
941    RETURN T
951    FNEND
961    DEF FNTvsv58(V)
971    COM /Cc58/ T58(5)
981    T=T58(0)
991    FOR I=1 TO 5
```

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```
8001   T=T+T58(I)*V^I
8011   NEXT I
8021   RETURN T
8031   FNEND
```

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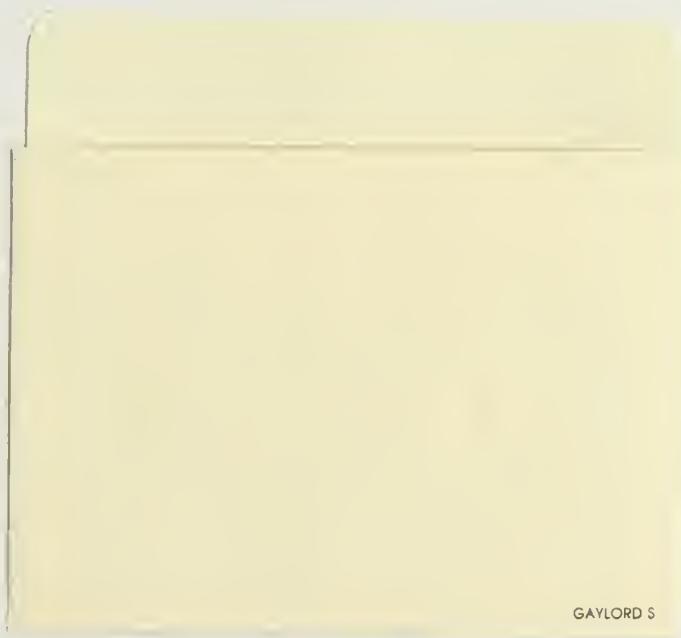
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